DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

6 JUN 2005

FROM: AFCESA/CES
139 Barnes Drive, Suite 1
Tyndall AFB FL 32403-5319

SUBJECT: **Engineering Technical Letter (ETL) 05-2: Design, Construction, Maintenance, and Evaluation of the McMurdo Sound Sea Ice Runway for Heavy Wheeled Aircraft Operations**

1. Purpose. This ETL provides design, construction, and maintenance details, dimensional criteria, and structural evaluation guidance for operations of heavy wheeled aircraft at the Sea Ice Runway located on McMurdo Sound near McMurdo Station, Antarctica. This runway is operated by the U.S. Antarctic Program (USAP) and primarily supports Air Force aircraft. Two potential surface conditions are considered: in the first, aircraft operate on an exposed sea ice runway; while in the second case, operations are conducted from a thin (less than 130 millimeters [5 inches] thick) processed snow pavement (white ice) overlying the sea ice. A minimum level of white ice strength is prescribed for the second case. The dimensional criteria are the same for either surface condition. The Sea Ice Runway has previously supported C-130 Hercules, C-141 Starlifter, C-17 Globemaster III, and C-5 Galaxy aircraft. For many years, C-130, C-141, and C-17 aircraft have performed routine operations from an exposed sea ice surface; since 2002, they have operated on a white ice pavement overlying the sea ice surface.

These criteria are written specifically for the Sea Ice Runway site in Antarctica. This site does not meet the requirements for a Class B runway. Additionally, some terminology used herein (i.e., in the tables on dimensional requirements) differs from that used in Unified Facilities Criteria (UFC) 3-260-01, *Airfield and Heliport Planning and Design*. The concepts are generally applicable to any runway composed of sea ice, with or without a thin compacted snow layer.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this ETL does not imply endorsement by the Air Force.

2. Application: All Department of Defense (DOD) and USAP (managed by the National Science Foundation [NSF]) organizations responsible for the design, construction, maintenance, and evaluation of the McMurdo Sound Sea Ice Runway.

2.1. It is anticipated that all field measurements and data collection prescribed in this ETL can and will be accomplished by knowledgeable personnel within the USAP and deployed to Antarctica as part of their occupational performance. This does not preclude Air Force certification teams traveling to McMurdo Station to complete an evaluation; however, due to the logistics, coordination, cost, and uncertain nature of travel to and work in Antarctica, it is more likely that the USAP McMurdo Area

Airfields Manager will be responsible for following all ETL guidelines for data collection.

2.2. Only Headquarters Air Mobility Command (HQ AMC) can determine the suitability of the airfield for operations of HQ AMC aircraft. It will be the USAP McMurdo Area Airfields Manager's responsibility to deliver all data and measurements, in the format prescribed in this ETL, to the HQ Civil Engineering Operations Division, Infrastructure Support (AMC/A7OI) contact (see paragraph 10) or his designee. HQ AMC will review the submittal and communicate its findings and decisions back to the airfields manager, who will be responsible for any remedial actions and communicating the airfield status (e.g., open, closed, open with restrictions) to all impacted operational elements. When HQ Civil Engineering Operations Division determines that the airfield meets the criteria specified in this ETL, HQ Operations (AMC/A36AS) will be notified, and they, in turn, will give approval for aircraft operations.

2.3. Authority: Air Force Policy Directive (AFPD) 32-10, *Installations and Facilities*.

2.4. Effective Date: Immediately.

2.5. Ultimate Recipients:

- Air Force civil engineers, USAP, and contractors responsible for the planning, design, construction, maintenance, and evaluation of airfields.
- U.S. Army Corps of Engineers (USACE) and DOD offices responsible for the planning, design, maintenance, and construction of airfields.

2.6. Coordination: HQ Air Mobility Command, Civil Engineering Operations Division, Infrastructure Support (HQ AMC/A7OI).

3. References:

3.1. Air Force:

- AFPD 32-10, *Installations and Facilities*, available at http://www.e-publishing.af.mil/afpubs.asp
- Air Force Manual (AFMAN) 32-1076, *Design Standards for Visual Air Navigation Facilities*, available at http://www.e-publishing.af.mil/afpubs.asp
- ETL 02-16, *Design, Construction, Maintenance, and Evaluation of the Pegasus Glacial Ice Runway for Heavy Wheeled Aircraft Operations*, available at http://www.afcesa.af.mil/library/etl.asp?Category=Engineering%20Technical%20Letters

3.2. Army:

- Cold Regions Research and Engineering Laboratory (CRREL) Monograph 98-1, *Construction, Maintenance, and Operation of a Glacial Runway, McMurdo*

Station, Antarctica, available at http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/M98_01.pdf

- CRREL Technical Report 153, *Study of the Rammsonde for Use in Hard Snow*
- FM 5-430-00-1, *Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations – Road Design,* available at https://atiam.train.army.mil/soldierPortal/atia/adlsc/view/public/8411-1/fm/5-430-00-1/toc.htm
- FM 5-430-00-2, Appendix J, *Description and Application of Dual Mass Dynamic Cone Penetrometer*, available at https://atiam.train.army.mil/soldierPortal/atia/adlsc/view/public/4695-1/fm/5-430-00-2/Appj.htm

3.3. Navy:

- Naval Civil Engineering Laboratory Report, *Nomographs for Operating Wheeled Aircraft on Sea-Ice Runways: McMurdo Station, Antarctica,* presented at the Third International Conference on Ice Technology, Cambridge, MA
- Naval Facilities Engineering Service Center, *Landing and Parking Curves for the C-17 Globemaster on Sea Ice: McMurdo Station, Antarctica,* available in Proceedings of the Seventh (1997) International Offshore and Polar Engineering Conference
- Vaudrey, K. 1977, *Ice Engineering – Study of Related Properties of Floating Sea-Ice Sheets and Summary of Elastic and Viscoelastic Analyses*, U.S. Naval Construction Battalion Center, Port Hueneme, CA, Civil Engineering Laboratory, Technical Report R-860

3.4. Joint Service:

- UFC 3-260-01, *Airfield and Heliport Planning and Design*, available at http://65.204.17.188//report/doc_ufc.html

3.5. American Society for Testing and Materials (ASTM):

- ASTM D1883-99, *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*, available at http://www.astm.org

3.6. American Society of Mechanical Engineers

- Barthelemy, J, 1992, *Nomographs for Operating Wheeled Aircraft on Sea-Ice Runways: McMurdo Station, Antarctica*, 11th International Conference on Offshore Mechanics and Arctic Engineering, Calgary, Alberta, June 7-12, 2002, Proceedings, Vol. 4. Edited by Ayorinde, Sinha, Sodhi, and Nixon, p. 27-33, published by the American Society of Mechanical Engineers, New York.

4. Acronyms.

AFJPAM - Air Force Joint Pamphlet

AFMAN	- Air Force Manual
AFPD	- Air Force Policy Directive
ASTM	- American Society for Testing and Materials
CBR	- California Bearing Ratio
CRREL	- US Army Cold Regions Research and Engineering Laboratory
DCP	- dynamic cone penetrometer
DO	- Director of Operations
DOD	- Department of Defense
ETL	- Engineering Technical Letter
ft	- foot
HQ AFCESA	- Headquarters, Air Force Civil Engineer Support Agency
HQ AMC/A7OI	- Headquarters, Air Force Mobility Command, Civil Engineering Operations Division, Infrastructure Support
HQ AMC/A36AS	- Headquarters, Air Force Mobility Command, Operations Division
in	- inch
kPa	- kilopascals
MAJCOM	- major command
m	- meter
MMLS	- Mobile Microwave Landing System
MOG	- maximum on ground
NAVAIDS	- navigational aid system
NCEL	- Naval Civil Engineering Laboratory
NSF	- National Science Foundation
PAPI	- precision approach path indicator
PCASE	- Pavement Computer Assisted Structural Engineering
PLZ	- prepared landing zone
psi	- pounds per square inch
REILS	- runway end identifier lights
RSP	- Russian snow penetrometer
TACAN	- Tactical Aid to Navigation
VFR	- visual flight rules
UFC	- Unified Facilities Criteria
US	- United States
USACE	- US Army Corps of Engineers
USAP	- United States Antarctic Program

5. Definitions. Some definitions critical to or unique to this ETL are given below.

5.1. *California Bearing Ratio (CBR):* An index test of soil strength determined using a 1935.5-square-millimeter (3-square-inch) piston forced into the soil. The load required to achieve a 2.5- or 5-millimeter (0.1- or 0.2-inch) penetration (whichever provides the lowest CBR value) is compared to a standard load for similar penetrations into a well-graded crushed aggregate. The test is widely used for military structural airfield assessments, and test procedures may be found in American Society for Testing and Materials (ASTM) D1883-99, *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*.

5.2. *Dynamic Cone Penetrometer (DCP):* The DCP is a portable soil field test device to allow rapid measurement of soil strength. An 8-kilogram (17.6-pound) or 4.6-kilogram (10.1-pound) sliding hammer is used to drive a 60^{o}, 20-millimeter- (0.8-inch) diameter cone into the soil. The DCP strength index, in units of millimeters per blow, is calculated as:

$$\text{DCP Index} = (P/N)\ F$$

where P is the accumulated cone penetration (in millimeters) after each set of N hammer blows, and F is a configuration factor (F=1.0 for 8-kilogram sliding hammer; F=1.742 for 4.6-kilogram sliding hammer). The DCP strength index has been correlated to other more time-consuming tests like CBR and is widely used in the military for expedient soil strength assessments for roads and airfields. A complete description of the DCP and its use are contained in Army FM 5-430-00-2, Appendix J, *Description and Application of Dual Mass Dynamic Cone Penetrometer*. See Attachment 1 for penetrometer user information.

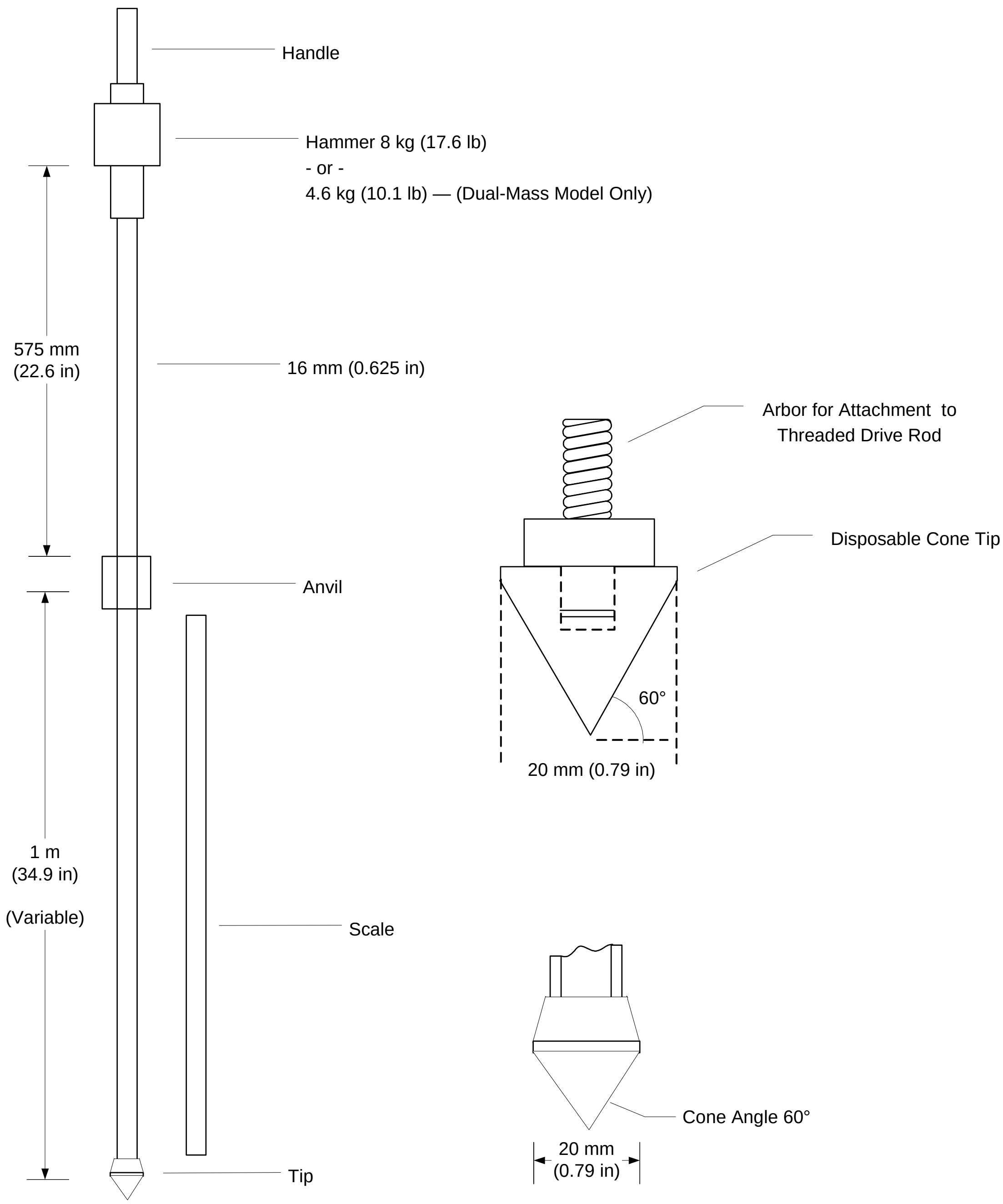

Figure 1. Dynamic Cone Penetrometer (DCP)

5.3. *Sea Ice Runway Surface:* The original exposed or level-graded surface of a floating slab of naturally frozen seawater.

5.4. *Non-Instrument Runway:* A runway intended for operating aircraft under visual flight rules (VFR). Routine operations at the Sea Ice Runway only occur when sunlight is present; this is roughly from late August until late March each year in the McMurdo Sound area.

5.5. *Prepared Landing Zone (PLZ):* For the purposes of this ETL, a prepared landing zone (PLZ) refers to a landing zone that is constructed to support routine and moderately frequent (average 1 to 2 flights per day) wheeled cargo aircraft traffic, with no adverse effect on airframes, but that is not paved with traditional construction materials (i.e., asphalt or concrete). The amount of engineering effort required to develop a PLZ depends on the planned operation and the existing surface and weather conditions. Options for surface preparation are governed by the material present at the site and may, at the Sea Ice Runway site, include plowing, grading, planing, and roller compaction.

5.6. *Processed Snow Pavement:* A durable weather- and abrasion-resistant surface made from grading and processing (e.g., compaction or tilling) natural snow that overlies a firm established base like sea ice. For the support of heavy wheeled aircraft, the processed snow must have reached a condition where it can be called white ice.

5.7. *Russian Snow Penetrometer (RSP):* The RSP is a portable test device for rapidly measuring snow strength. A 1.75-kilogram (3.85-pound) sliding hammer is dropped from a height of 500 millimeters (19.7 inches) to drive into the snow a 30^{o} cone with a maximum diameter of 11 millimeters (0.4 inch). During a test, penetration distance and the number of blows to produce it are recorded. The RSP index, in units of kilograms, is calculated as:

$$\text{RSP Index} = (W \cdot h \cdot n \cdot L^{-1}) + W + Q$$

where W is the mass of the drop hammer (kilograms), h is the height of the hammer drop (millimeters), n is the number of hammer blows to generate L (millimeters) penetration, and Q is the total mass of the penetrometer (kilograms) less its hammer. Details of penetrometer testing in processed snow can be found in CRREL Technical Report 153, *Study of the Rammsonde for Use in Hard Snow*. See Attachment 1 of this ETL for penetrometer user information.

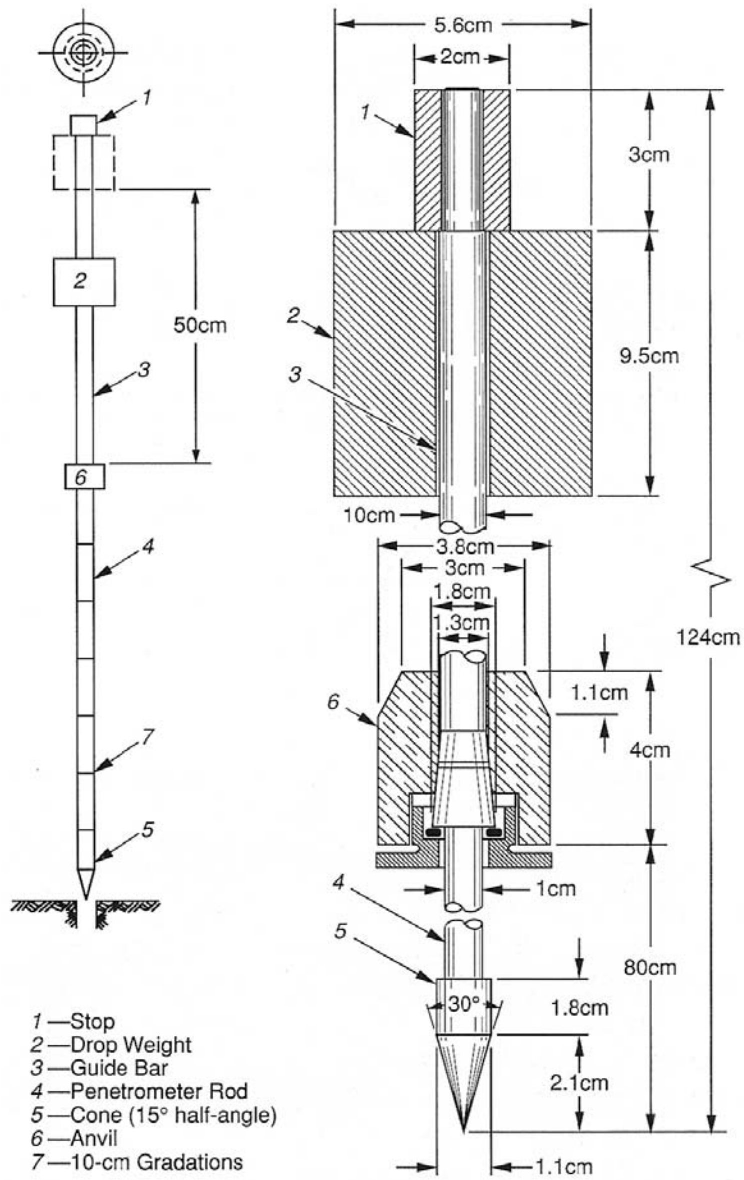

Figure 2. Russian Snow Penetrometer (RSP)

5.8. *Seasonal Operations:* Typically, short-term operations conducted in support of specific local activities. Seasonal operations denote aircraft activities being confined to certain periods of the year when flight and runway conditions are most favorable and when airlift is required. The Sea Ice Runway is only operated when (a) air temperatures are above -50 °C (-58 °F), (b) sunlight is present, and (c) when ice thickness and strength combine to allow safe landing and parking.

6. Dimensional Criteria. Details for establishing airfields for the support of routine operations of Air Force aircraft can be found in UFC 3-260-01. The Sea Ice Runway is unique in a number of ways: seasonal operation only; low volume of air traffic; extremely remote location; sited on a large floating ice mass; limited resources available for construction and maintenance. The criteria are based, for the most part, on Class B runway requirements; however, some terminology used in this ETL differs from that used in UFC 3-260-01.

6.1. Table 1 provides dimensional criteria for the layout and design of the PLZ at the Sea Ice Runway site. Minimum runway length is prescribed by the major command director of operations (MAJCOM/DO), but should be 3048 meters (10,000 feet) for fully loaded aircraft operations, assuming that the braking conditions are adequate. When the Sea Ice PLZ exists with a thin processed snow pavement, the same length requirements exist, **assuming** that the processed snow pavement meets its structural requirements. Note that runway strength, as measured by DCP or RSP, can vary as a function of air temperature and insolation (solar energy input). Properly executed maintenance operations can mitigate this deterioration and keep the strength at or above minimum levels. The runway length shown in Table 1 also recognizes that the Sea Ice PLZ is at sea level.

Table 1. Sea Ice Runway Dimensional Requirements for C-130, C-141, C-17, and C-5 Operations

	Description	**Natural or Graded Sea Ice, or Processed Snow (White Ice) Operating Surface**	**Remarks**
1	Length (minimum)	See Remarks	Minimum runway length will be determined by the MAJCOM/DO for the most critical aircraft in support of the mission. At the Sea Ice Runway, a runway length of 3048 m (10,000 ft) is considered adequate for all routine operations with C-130, C-141, C-17, and C-5 aircraft.
2	Width	45.7 m (150 ft)	
3	Width of shoulders (minimum)	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. All white ice in shoulders should be prepared to required runway strength standards and, for a white ice surface, be less than 130 mm (5 in) in depth.
4	Longitudinal grade	2% maximum (up or down)	The maximum grade of any tangent, as well as the total elevation change from one threshold of the runway to the other, should not exceed 2%.

5	Longitudinal grade change	No grade change greater than 0.5% is to occur within 305 m (1000 ft) of the runway end.	Hold to minimum practicable. Grades may be both positive and negative but must not exceed the limit specified. Applies to runway and shoulders.
6	Rate of longitudinal grade change	Maximum 0.167% per 30.5 m (100 ft) interval.	Grade changes should be held to a minimum and should be gradual. Application of this criterion will produce a vertical curve having a 182.9 m (600 ft) length for each percent of algebraic difference between the two grades. Applies to runways and shoulders.
7	Transverse grade of runway	1.5% maximum	Transverse grades can be a uniform slope, or crowned at the centerline (a crowned centerline is preferred).
8	Transverse grade of shoulders	2% maximum (down)	For an exposed ice surface, transverse grades should slope down from the runway edge. A white ice surface may slope upward to a maximum extent of 1%.
9	Width of graded area	Minimum 12.2 m (40 ft)	The graded area is measured from the outside edge of the shoulder. Graded area should have no more than 100 mm (4 in) of loose snow cover.
10	Transverse grade of graded area	2% maximum (up or down)	Ideally, graded area slope (up or down) should match that of runway shoulders.
11	Width of lateral clear area	79.2 m (260 ft)	The lateral clear area is measured outward from the outside edge of the graded area.
12	Transverse grade of lateral clear area	12% maximum	Requirement is applied to a plane extending outward from the outer edge of the graded area a distance of 36.6 m (120 ft). No object or surface feature may penetrate this plane. Any slope is allowed from 36.6 to 79.2 m (120 to 260 ft) from the outside edge of the graded area (i.e., 79.2 to 122 m [260 to 400 ft] from the runway centerline). No object or surface feature may penetrate this imaginary plane.

13	Width of primary surface	243.9 m (800 ft)	Primary surface is centered about the runway and incorporates the runway, shoulder, graded area, and lateral clear area.

6.2. Shoulders are required along each outside edge of the runway. They must be prepared to the same strength as the runway surface (and be of the same surface material: white ice or sea ice) and be free of obstacles. Shoulder geometric requirements are presented in Table 1. Figure 3 shows the typical layout, including shoulders, and lateral and end clear areas. Turns may take place on the prepared surface, including the shoulders.

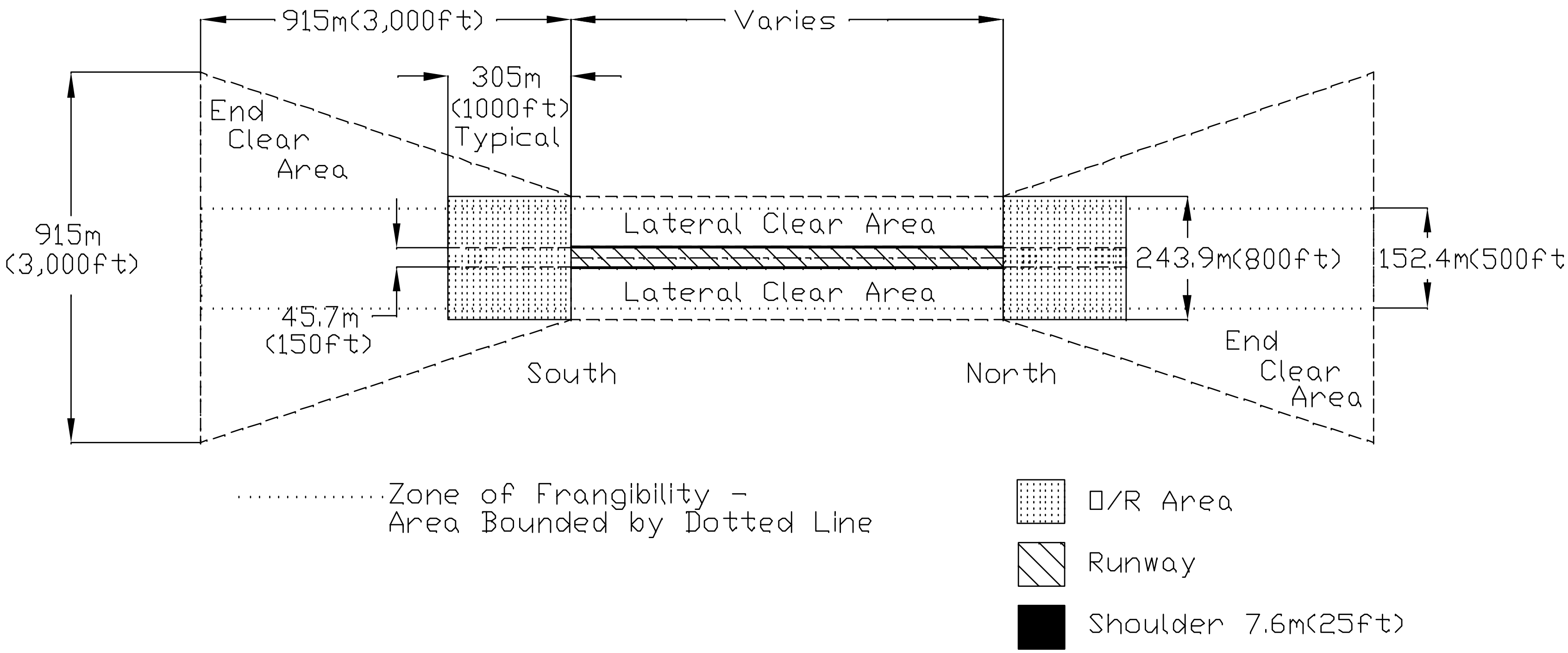

Figure 3. Typical Layout for Airstrip at McMurdo Sound Sea Ice Runway (Not to Scale)

6.3. A runway overrun is required at each end of the runway. The overrun must be 305 meters (1000 feet) in length and constructed to the same dimensional and structural standards as the runway surface.

6.4. Lateral and runway end clear areas are required and their dimensions are given in Table 2. The layout is shown in Figure 3.

Table 2. Sea Ice Runway Overrun and End Clear Area Requirements for C-130, C-141, C-17, and C-5 Operations

	Description	**Natural or Graded Sea Ice, or Processed Snow (White Ice) Operating Surface**	**Remarks**
1	End clear area length	915 m (3000 ft)	Measured along the extended runway centerline. Begins at the runway threshold.
2	Width of inner edge of end clear area	243.9 m (800 ft)	Centered about runway centerline. Begins at runway threshold.
3	Width of outer edge of end clear area	915 m (3000 ft)	Centered about runway centerline.
4	Runway overrun area	See Remarks	The runway overrun area falls within the runway end clear area. The overrun area will be 305 m (1000 ft) long and have a transverse section matching the runway (i.e., include shoulder, graded area, and lateral clear area). See Table 1 for transverse dimensional criteria. The maximum longitudinal grade (up or down) in the overrun area is 2%. The longitudinal grade of the first 91.5 m (300 ft) of the overrun should match that of the last 915 m (3000 ft) of the runway.

5	Approach departure clearance surface	50:1	Approach-departure clearance surface begins at the runway thresholds at the same elevation as the centerline elevation and extends away from the runway 7622 m (25,000 ft). During flight operations, no mobile or fixed object may penetrate this imaginary plane within the end clear area.

6.5. Taxiways, if present, will have surface strength properties matching those of the runway. Dimensional criteria for taxiways are given in Table 3.

Table 3. Sea Ice Taxiways (If Present) Dimensional Requirements for C-130, C-141, C-17, and C-5 Operations

	Description	Natural or Graded Sea Ice, or Processed Snow (White Ice) Operating Surface	Remarks
1	Width	22.9 m (75 ft) minimum	
2	Radius of curves (C-130, C-141, C-17, C-5)	22.9 m (75 ft) minimum	Curves in taxiway must be no tighter than the listed minimum turning radii, measured along the taxiway centerline. Fillets at runway/taxiway/apron turns and/or intersections must be 30.5 m (100 ft) minimum radii.
3	Width of shoulder	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. Snow in shoulders will be prepared to the same strength as the taxiway.
4	Longitudinal grade	3% maximum	Hold to minimum practicable. Grades may be either positive or negative.
5	Rate of longitudinal grade change	1% maximum over 30.5 m (100 ft)	Grade changes should be held to a minimum and should be gradual. Minimum distance between grade changes is 152.4 m (500 ft). Grade changes cannot exceed 1% measured at 30.5-m (100-ft) intervals. Applies to taxiway and shoulders.

6	Transverse grade of taxiway	3% maximum	Transverse grades can be a uniform slope, or crowned at the centerline (a crowned centerline is preferred).
7	Transverse grade of shoulders	3% maximum	For an exposed ice surface, transverse grades should slope down from the taxiway edge. A white ice surface may slope upward to a maximum extent of 1%.
8	Runway clearance	76.2 m (250 ft)	Measured from the runway centerline to near edge of the taxiway. Operating aircraft are exempt from runway/taxiway clearance requirements, but operational controls should be implemented to prevent aircraft from operating on both surfaces simultaneously.
9	Infield area		All areas located between the runway and taxiways must be cleared of obstructions.
10	Clearance to fixed or mobile obstacles	61 m (200 ft)	Measured from the taxiway centerline. Operating aircraft are exempt from runway/taxiway clearance requirements, but operational controls should be implemented to prevent aircraft from operating on both surfaces simultaneously.
11	Width of lateral clear area	41.9 m (137.5 ft)	Lateral clear area is measured outward from the outer edge of the shoulder. No object or surface feature may penetrate this imaginary plane.
12	Transverse grade of lateral clear area	12% maximum	Grades may slope up or down.

6.6. Aprons, if present, will have surface strength properties matching those of the runway. Dimensional criteria for aprons are given in Table 4 and plan views of appropriate apron configurations are provided in Figure 4.

Table 4. Sea Ice Site Apron Requirements for C-130, C-141, C-17, and C-5 Operations

	Description	Natural or Graded Sea Ice, or Processed Snow (White Ice) Operating Surface	Remarks
1	Apron size	Varies	Sized to accommodate number of aircraft on ground. Maximum visibility and minimum wingtip clearance must be maintained at all times. As a minimum, the pilot must be able to clearly see all parked aircraft when taxiing.
2	Apron grade	3% maximum	Ideally, uniform grade should exist over entire apron area.
3	Width of shoulder	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. Snow in shoulders will be prepared to the same strength as the apron.
4	Transverse grade of shoulders	3% maximum	For an exposed ice surface, transverse grades should slope down from the runway edge. A white ice surface may slope upward to a maximum extent of 1%.
5	Runway clearance	122 m (400 ft)	Measured from the runway centerline to the near edge of the parking apron.
6	Clearance to fixed or mobile obstacles	38.1 m (125 ft)	Measured from the outer edge of the apron.
7	Width of lateral clear area	30.5 m (100 ft)	Lateral clear area is measured outward from the outer edge of the shoulder. No object or surface feature may penetrate this imaginary plane.
8	Transverse grade of lateral clear area	12% maximum	Grades may slope up or down.
9	Wingtip clearance	15.2 m (50 ft)	Parked and taxiing aircraft must maintain no less than 15.2 m (50 ft) wingtip clearance at all times.

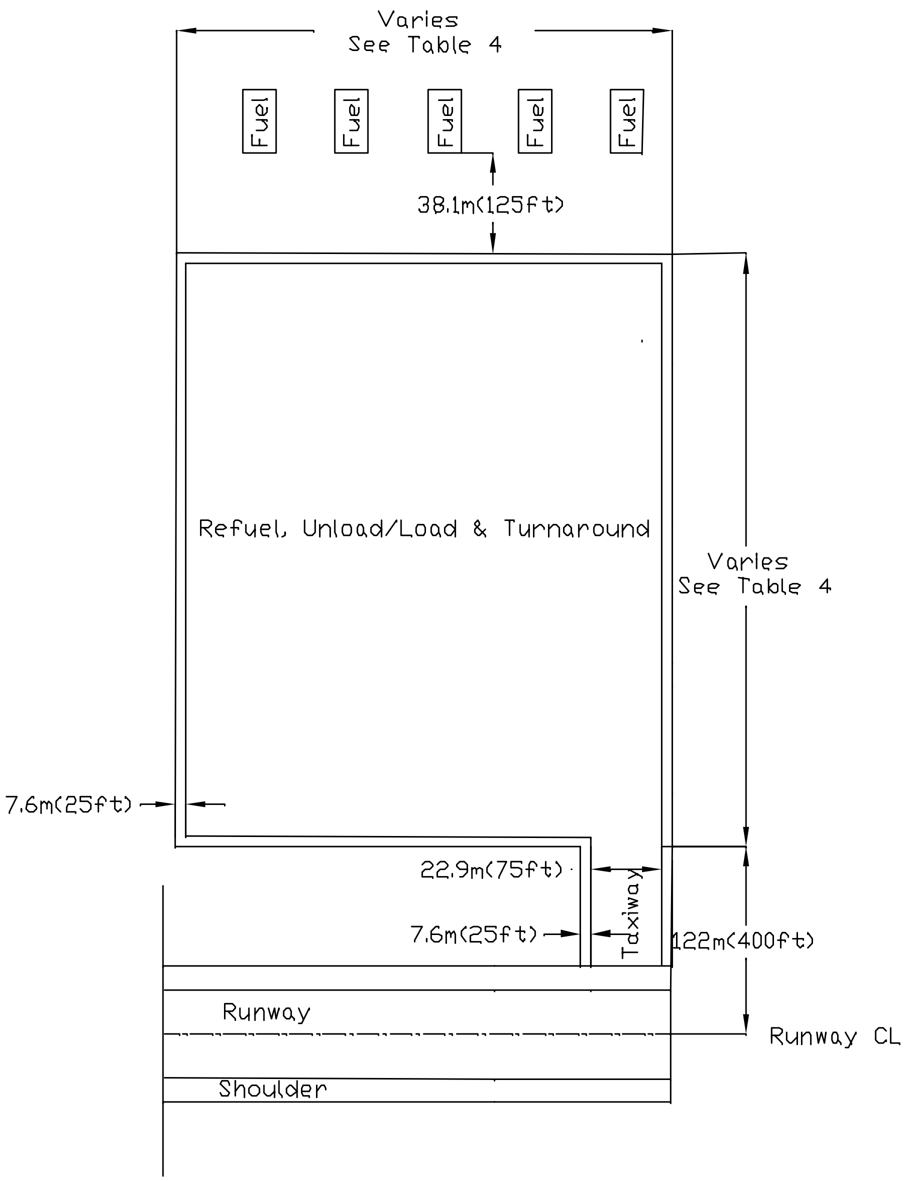

Figure 4. Typical Layout Arrangements for Taxiway and Apron (Not to Scale)

6.7. See Figure 5 for cross-section views of the runway, taxiway, and apron, showing the dimensions from Tables 1, 2, and 3.

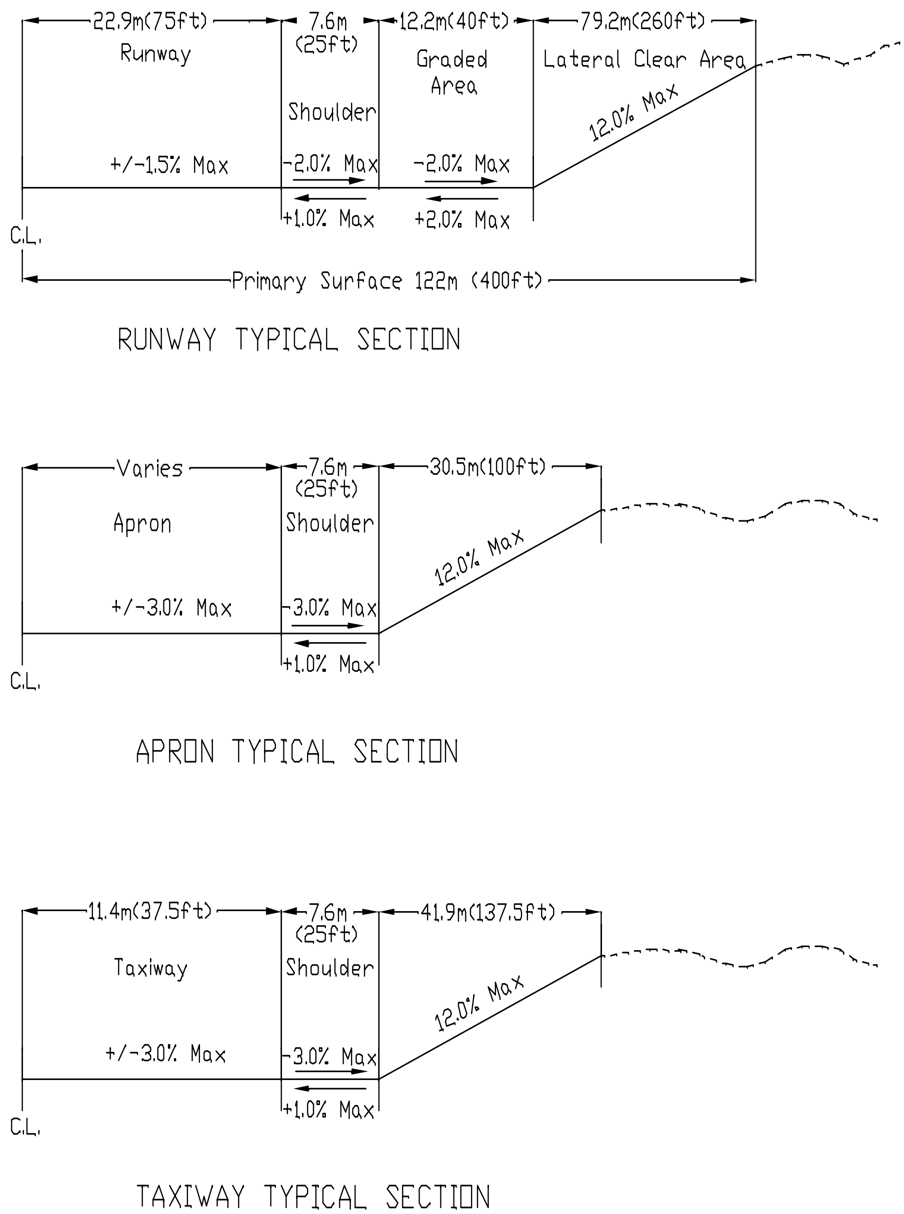

Figure 5. Typical Cross-Section Dimensions for Runway, Taxiway, and Apron (Not to Scale)

7. Structural Criteria

7.1. Sea ice is often categorized as first-year or multi-year ice. This characterization of the ice indicates much about its nature, with multi-year ice having significantly greater complexity. However, for the purposes of a sea ice runway for heavy wheeled aircraft, this ETL will treat both types the same, using overall ice thickness and ice temperature as governors for ice strength, which ultimately determines its ability to support a given aircraft operation.

Annually, before commencing aircraft operations (usually, flights on the Sea Ice Runway begin in early October each season), the Sea Ice Runway will be evaluated using the structural evaluation criteria in this ETL. In addition, the airfields manager will conduct interim evaluations for quality assurance and validation of localized repairs.

7.2. Sea Ice Operating Surface (less than 30 millimeters [1.2 inches] of snow cover present).

7.2.1. Sea Ice Runway Surface Evaluation—Deformation Failure. The sea ice surface must be shown to be capable of supporting C-130, C-141, C-17, and C-5 aircraft contact pressure levels without compressive or shear failure. The primary sources of ice surface weakness at the Sea Ice Runway site are (a) melt-pockets and (b) brine leaching features. When these occur, they may show minimal surface expression and may give the runway a deceptive appearance of strength. Rigorous maintenance can avoid melt problems. Brine leaching occurs as a function of time, and such weak areas may become prevalent as the runway is sited on progressively older (multi-year) sea ice. Generally, brine leaching features will not reach a point of concern for a sea ice runway until the ice is four years of age or older. If there is any doubt, or if the conditions described in paragraph 7.2.1.1 apply, the runway's structural strength must be certified daily. Adequate surface strength will generally be demonstrated by proof rolling to detect zones of weakness.

7.2.1.1. Proof Rolling. Proof rolling tests are required before the first flight of the season for both types (snow-covered and exposed surface) of sea ice runways (see CRREL Monograph 98-1). Additionally, proof rolling is required any time the surface temperature in the ice (measured at a depth of 10 millimeters [0.5 inch]) rises above –5 °C (23 °F) when the runway has an exposed sea ice surface, or –3 °C (26 °F) when the runway has a white ice pavement in place. (Ideally, temperature is measured by solar-shielded, continuously recording temperature probes buried in the ice). Any time the ice temperature reaches or exceeds the limits stated, the potential exists for melt-pocket formation and the runway surface must be inspected ***daily*** for such potential melt-damaged areas by proof rolling. Perform the test with pneumatic tire(s) with a minimum inflation pressure of 7.7 kilograms per square centimeter (760 kilopascals or 110 pounds per square inch), but preferably at an inflation pressure of 10.5 kilograms per square centimeter (1034 kilopascals or 150 pounds per square inch). The vehicle should have a minimum individual tire load of 16,000 kilograms (35,000 pounds). Coverage should be at no greater than 1-meter (3-foot) lateral spacing over the entire width of the runway and shoulder surface. Successful proof rolling will generate no ice cracking which results in a removable ice piece larger than 0.3 meter by 0.3 meter by 0.05 meter deep (12 inches by 12 inches by 2 inches deep). Any defective areas discovered will be removed, repaired, and retested according to the process outlined in Attachment 3.

7.2.1.2. If the ice temperature exceeds –5 °C (23 °F; exposed sea ice surface) or –3 °C (26 °F; white ice pavement in place) while in the midst of an operation period having a frequency of flights of at least every other day, then a rigorous daily visual inspection, especially in the aircraft wheel tracks, will suffice for proof rolling. However, any surface failure detected will immediately trigger a full proof rolling in accordance with paragraph 7.2.1.1.

7.2.2. Sea Ice Runway Surface Evaluation—Flexural Failure (Landing and Take-Off).

7.2.2.1. Flexural strength of sea ice is a function of ice temperature, ice thickness and salinity. Correspondingly, the maximum load capacity of sea ice under aircraft loads is a function of flexural strength and the landing-gear-assembly geometry of each aircraft. Determining the maximum allowable aircraft load from ice thickness and temperature measurements establishes the load capacities for landings and takeoffs on the Sea Ice Runway. Collecting ice temperature measurements through the entire ice sheet at many locations on a frequent basis along the Sea Ice Runway is onerous, so seasonal time periods have been established to simplify the analytical process. The method combined ice *surface* temperatures into "bins," such that each "bin" represents a period of the operational season. Each time-period contains a maximum and minimum *surface* temperature. Current guidelines divide the operational season (October to February) into four periods:

- Mid-October to late November (Period 1: -20 °C to -10 °C [-4 °F to 14 °F])
- Late November to mid-December (Period 2: -10 °C to -5 °C [14 °F to 23 °F])
- Mid-December to late December (Period 3: -5 °C to -2 °C [23 °F to 28 °F])
- Late December through January (Period 4: -3 °C to -2 °C [26 °F to 28 °F]).

Collect ice temperatures (measured at a depth of 10 millimeters [0.5 inch]) at least ***weekly*** at the airfield locations prescribed in Attachment 4 (paragraph A4.2.5) to verify that the calendar-suggested period is confirmed by ice temperatures (in all cases, actual ice temperatures will govern which period's standards to apply).

7.2.2.2. Maximum allowable stresses were developed for each of the four operational periods using a computer program designed to calculate the flexural beam strength of sea ice. Since the salinity content of sea ice in McMurdo Sound is constant across all operational periods, the allowable stresses were calculated as a function of temperature only. The allowable stresses have factors of safety between 1.3 and 1.4 (25% to 30% of flexural strength).

7.2.2.3. Maximum allowable stresses calculated for the four periods of the operational season, combined with ice thickness and landing-gear-assembly geometry, were input to a model developed by the Naval Civil Engineering Laboratory (NCEL) to predict the maximum allowable load of C-130, C-141, C-17 and C-5 aircraft operating on the sea ice in McMurdo Sound. A range of sea ice thickness values experienced throughout the operational season were input and the model calculated the maximum allowable aircraft load given as a function of the Sea Ice Runway thickness and the period of operation. Results from the model are presented in Figure 6 and constitute the landing, taxiing, and take-off operational strength criteria. The curves in Figure 6 were developed based on the parameters described above, and each is specific to aircraft type and gear assembly geometry. The Figure 6 nomograph may be worked from either direction; that is, if one knows the ice thickness and aircraft type to be operated, the maximum landing and take-off load may be calculated. Conversely, knowing what aircraft type and load are desired to be flown to/from the Sea Ice Runway, the required ice thickness can be determined. Actual ice thickness must be measured at 16 locations (see Attachment 4, Figure A4.1 for thickness measurement points) ***weekly***, starting at least three weeks before the intended onset of flight operations. Measurements will continue throughout the entire duration of flight operations.

Notes:

(1) The charts are specific to each aircraft and cannot be used for any other aircraft. Other aircraft of interest will require a new model run to develop allowable load/thickness curves (see paragraph 10 for contact information if a new analysis is needed).

(2) Examples of nomograph use are provided in Attachment 2. See Attachment 5 for metric conversion factors.

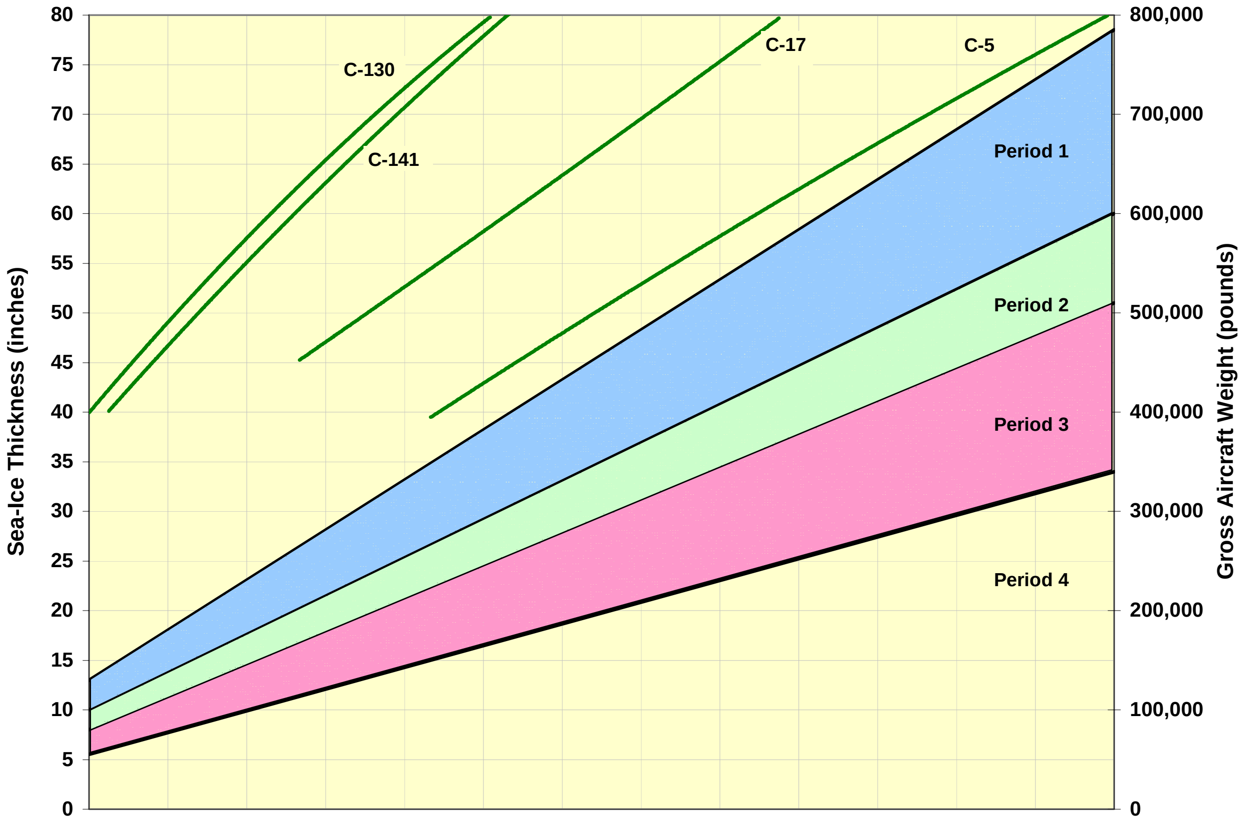

Figure 6. Landing and Take-off Nomograph for the McMurdo Sound Sea Ice Runway (See Attachment 2 for usage directions and Attachment 5 for metric conversion factors)

7.2.3. Sea Ice Runway Surface Evaluation—Creep Failure (Parking). Long-term parking at warm ice temperatures can lead to creep deformation of the sea ice. Long-term parking is defined here to mean any time an aircraft is stationary anywhere on sea ice more than 30 minutes. At ice temperatures below –5 °C (23 °F), creep deformation is relatively slow. Since the Sea Ice PLZ is operated principally as a “turn-around” runway (i.e., arriving aircraft debark within a few hours, spending limited time onsite), it is expected that creep deformation will be negligible. However, if aircraft will be parked for extended time periods, or very heavy loads or thin ice conditions are present, aircraft may have to be moved periodically to avoid excessive creep deformation of the sea ice. A maximum allowable deflection limit of 10% of the ice thickness has been set for parked aircraft. Field tests indicate no major cracking or failures on sea ice until deflections are in excess of 25% of the ice thickness (Vaudrey, 1977). The 10% deflection value was selected because this is the freeboard limit for the ice sheet; although the ice is safe at this point (10% deflection), water could penetrate through existing cracks and holes to the runway surface, raising concern and causing operational difficulties (Barthelemy, 1992). Parking curves have been developed for each aircraft. The curves indicate the maximum time an aircraft can remain stationary as function of the period (ice temperature), ice thickness and aircraft type and load. The aircraft must change parking locations if it remains on the ice longer than indicated by the curves. The new parking position must be at least two overall aircraft widths removed from the original location. Operational strength criteria for aircraft parked on sea ice are presented in Figure 7.

Note: Examples of nomograph use are provided in Attachment 2. See Attachment 5 for metric conversion factors.

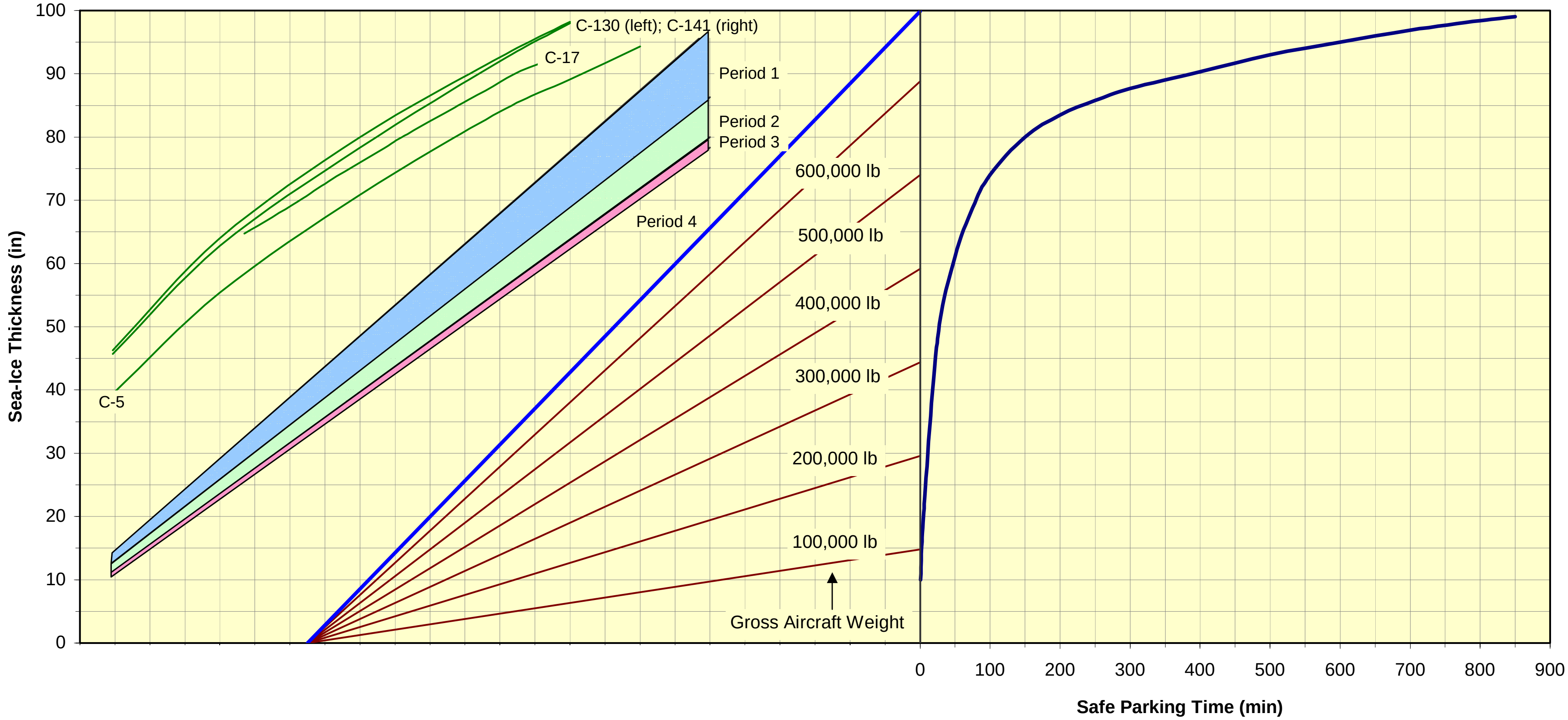

Figure 7. Allowable Parking Times for the McMurdo Sound Sea Ice Runway (See Attachment 2 for usage directions and Attachment 5 for metric conversion factors)

7.2.4.

> **WARNING**
>
> Both landing/take-off and parking criteria must be determined and compared before each aircraft operation. In most cases, the minimum required sea ice thickness will be different for landing/take-off and for parking. The **GREATER** of the two calculated thicknesses must be used in planning for the aircraft mission. At times, adjustment of one or more controllable variables can allow performing an aircraft mission that, as initially planned, would not be allowed. See examples in Attachment 2 for an illustration of this process.

7.2.5. The primary source of ice mass weakness at the Sea Ice Runway site is thinning and weakening during mid- to late-season operations as sea and air temperatures rise. Cracks may also form in the sea ice sheet at any point during the operational season due to tidal and other ice forces active in the region. Though not unsafe, the cracks may limit mobility and must be repaired before aircraft operations. The sea ice crack-repair procedure is described in Attachment 3.

7.2.6. This ETL is written specifically for C-130, C-17, C-141, and C-5 aircraft. The load capacity of the Sea Ice Runway changes according to aircraft landing-gear assemblies. Contact the person(s) listed in paragraph 10 for recommendations on how to proceed if operational needs are encountered when the ice thickness is below the minimum required for an aircraft, the surface temperatures are above the maximum for any period, or if a different type of aircraft or landing gear configuration is proposed for operation on the McMurdo Sound Sea Ice Runway.

7.3. Thin White Ice Operating Surface.

7.3.1. White Ice Pavement Thickness. This ETL is written for a maximum white ice pavement thickness of 130 millimeters (5 inches). This limitation to white ice thickness reflects the current level of understanding of its performance as a pavement for C-130, C-17, and C-141 aircraft (C-5 aircraft have yet to operate on white ice pavement). If white ice pavement thickness exceeds 130 millimeters (5 inches), one of the following actions must be taken:

7.3.1.1. Grade the surface back to the desirable thickness. (Grading should be done with a tool that avoids damage to the underlying material, e.g., a sharp-edge, slow-moving grader mouldboard blade.)

7.3.1.2. Contact the person(s) listed in paragraph 10 for recommendations on how to proceed.

7.3.2. White Ice Runway Surface—Deformation Failure. It is required that the sea ice (surface and flexural characteristics) be certified (paragraph 7.2 et seq.) as part of certification of a thin processed snow operating surface at the Sea Ice PLZ. Being a thin processed snow pavement overlying a sufficiently strong base, the principal structural requirement of the white ice is its ability to support tire contact pressures.

7.3.3. White Ice Runway Surface—Snow Pavement Strength Determination.

7.3.3.1. A penetration resistance index will be used as the basis for evaluating snow pavement strength. Measurements may be taken with either a DCP (see paragraph 5.2) or an RSP (see paragraph 5.7). See Attachment 1 for test procedures for both devices. The correlation between DCP and RSP index strengths is shown in Figure 8.

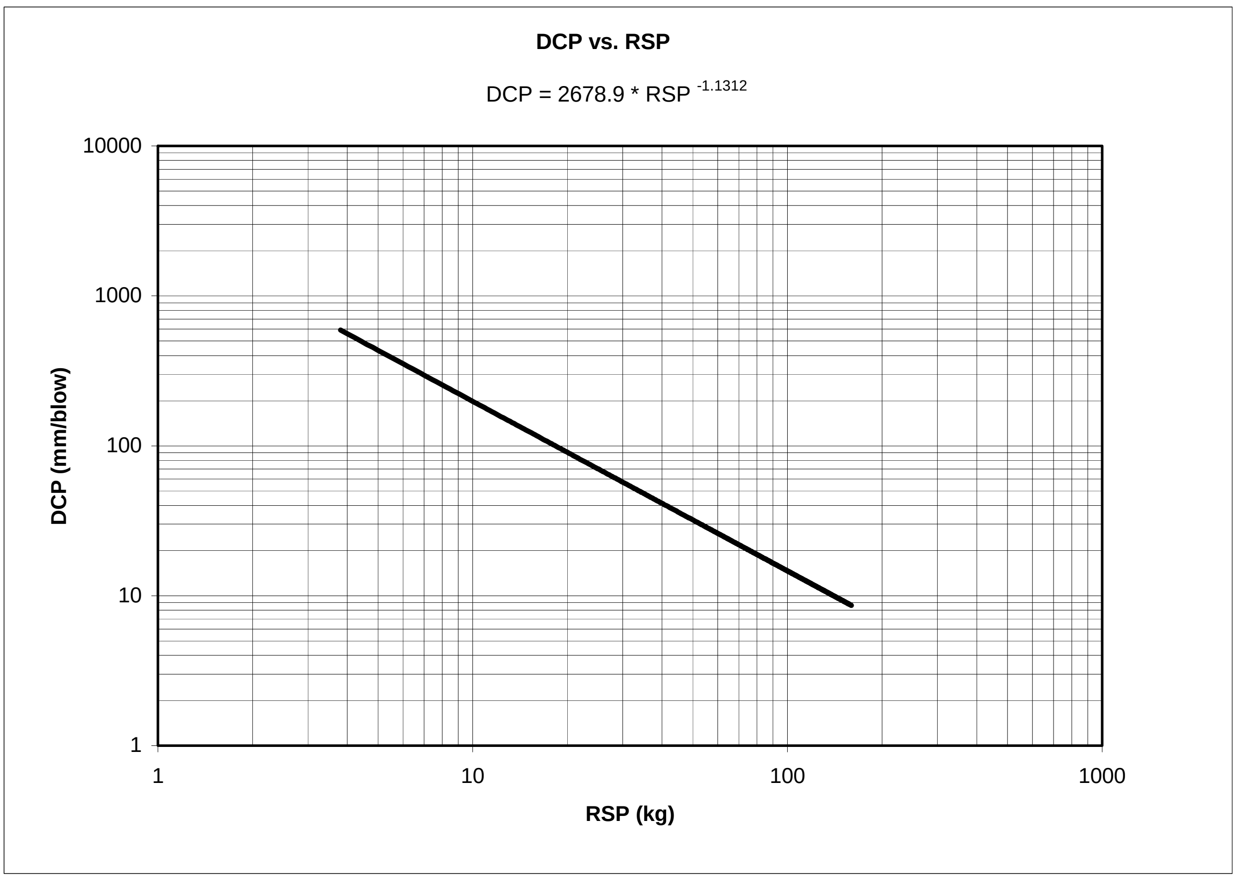

Figure 8. Correlation Between RSP and DCP

7.3.3.2. Executing a runway strength survey should follow the procedure given in Attachment 4. For the runway to be considered adequate for aircraft operations, two conditions must be met, as described in paragraphs 7.3.3.2.1 and 7.3.3.2.2.

7.3.3.2.1. The average of all individual penetrometer test site values must match or be stronger than the required mean strength value listed in Table 5 and shown graphically in Figure 9.

7.3.3.2.2. Eighty-five percent of the individual penetrometer test site values must match or be stronger than the lower strength limit values given in Table 5. However, if the majority of the 15% of values that do not meet the lower strength limit are localized, then maintenance activities are required in this area to increase its strength.

Table 5. Minimum Snow Strength Required for White Ice Pavement

Aircraft	Mean RSP Index	Lower RSP Strength Limit	Mean DCP Index	Lower DCP Strength Limit
C-130[1]	55	45	30	37
C-5[2]	56	45	29	36
C-17[3]	60	46	26	35
C-141[4]	67	49	23	33

[1] Tire pressure = 655 kilopascals (95 pounds per square inch)
[2] Tire pressure = 793 kilopascals (115 pounds per square inch)
[3] Tire pressure = 1068 kilopascals (155 pounds per square inch)
[4] Tire pressure = 1344 kilopascals (195 pounds per square inch)

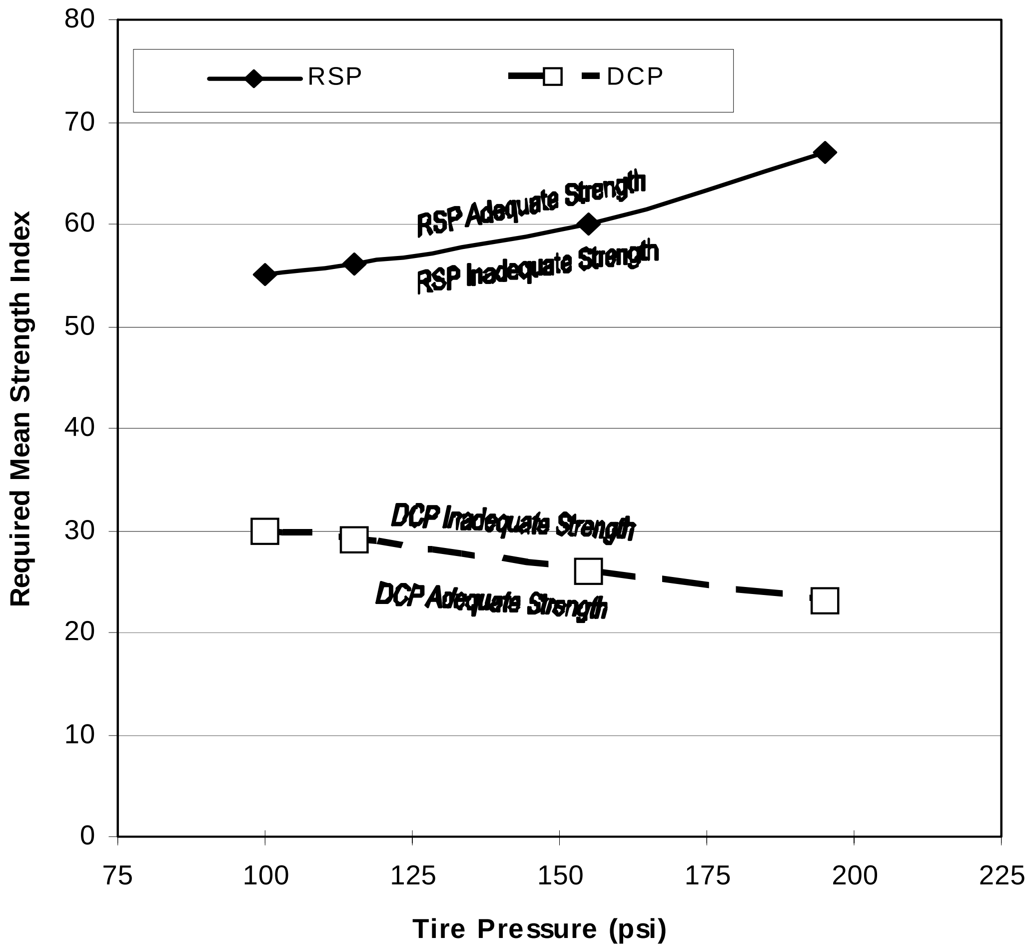

Figure 9. Strength Criteria for White Ice Pavement

7.3.3.3. Attachment 4 suggests a graphical method of quickly assessing the distribution of strength measurements using the *Ice Runway Strength Survey Tool* program (contact the individual(s) at NSF or USACRREL, listed in paragraph 10, for a copy of this Microsoft® Excel-based program).

Note: This approach makes it easier to locate regions of substandard snow strength so maintenance and repair activities can be quickly focused on trouble spots.

7.3.4. White Ice Runway Surface—Allowable Aircraft Loads/Contact Pressures.

7.3.4.1. Physical testing and aircraft validation activities in the McMurdo Sound area have established the minimum thin snow pavement strength levels for C-130, C-141, and C-17 operations. These are shown in terms of several parameters in Table 5. Note that with a thin processed snow pavement over a strong base material, white ice (snow pavement) strength requirements are sensitive to aircraft contact pressure (tire pressure) but quite insensitive to aircraft gross load (since tire and gear load is being supported by the base material). Thus, Table 5 values are for fully loaded or partially loaded aircraft operating at the noted tire pressures. Further, pavement strength for the C-5 is also given in Table 5 since its tire pressure falls within the range of other aircraft tested and can therefore be reliably extrapolated.

7.3.4.2. The allowable gross load and contact pressure will be applicable to aircraft both landing and taking-off. These criteria are based on a condition of negligible surface deformation or rutting. "Negligible" is defined here as surface damage in isolated areas and not exceeding 25 millimeters (1 inch) in depth. The values in Table 5 and Figure 9 are conservative with respect to the vertical bearing load of wheeled aircraft; the values chosen ensure that surface deformations do not occur as a result of other aircraft loads, particularly shear loading of the white ice when aircraft brake or turn sharply.

8. Markings and Navigational Aid System (NAVAIDS).

8.1. The McMurdo Sound Sea Ice Runway is a VFR-only facility and is operated solely during daylight. However, markings and NAVAIDS are required (a) due to the site's unconventional appearance (light gray to white surface, white surroundings), (b) for compatibility with standard pilot experience, and (c) for periods where landings are required but weather conditions are less than ideal. Initial operation of the Sea Ice Runway was accomplished with an absolute minimum of markings and no NAVAIDS. The use of both markings and NAVAIDS has evolved over the years, and is expected to continue into the future.

8.2. It cannot be overstated that adopting the full extent and type of markings and NAVAIDS found at a conventional airport would create an unmaintainable runway that would be buried by drifting snow in a few seasons. Nor is it necessary for the Sea Ice Runway to have the full complement of available markings and NAVAIDS.

Since the airspace is not congested and there are only a few well-known nearby topographic or human-made obstacles, it is operated as a VFR facility.

8.3. Minimizing the number and surface area of markings is desirable for the purpose of reducing runway maintenance and increasing runway availability and longevity. Figure 10 shows the layout of the Sea Ice Runway, including the positions of lead-in, lead-out, ground plane, distance remaining, and threshold and mid-point markers. All markers should be made of durable, lightweight materials. Support posts must be frangible and present a tiny cross-section to the wind to minimize snow drifting, which should be accomplished by a small diameter and a minimum number of posts; bamboo canes are currently used with good results. The markers are ideally of a broad-weave mesh material to minimize the impedance of the wind, both to limit wind loading on the support posts and, more importantly, to reduce snow drifting. Ideally, the base of a marker should be more than 1 meter (3 feet) above the snow surface to avoid snow drifting. This height must be balanced against the need for adequate clearance between the base of an aircraft wing, engine, or propeller and the top of the marker. Currently, black- and orange-colored plastic mesh fencing material, such as seen at construction sites and ski areas, is used for markers. Note that all markings are well above the runway surface, and no markings are present on the runway itself to depict the runway centerline, shoulder edges, landing zone, or thresholds.

8.4. All structures placed or constructed within the airfield environment are required to be made frangible (to the maximum extent practicable). This applies for any aboveground construction within 76.2 m (250 ft) of the runway centerline and an extension of that dimension for 915 m (3000 ft) beyond the ends of the runway thresholds and within 61 m (200 ft) of the taxiway centerline. Frangibility implies that an object will collapse or fall over after being struck by a moving aircraft with minimal damage to the aircraft.

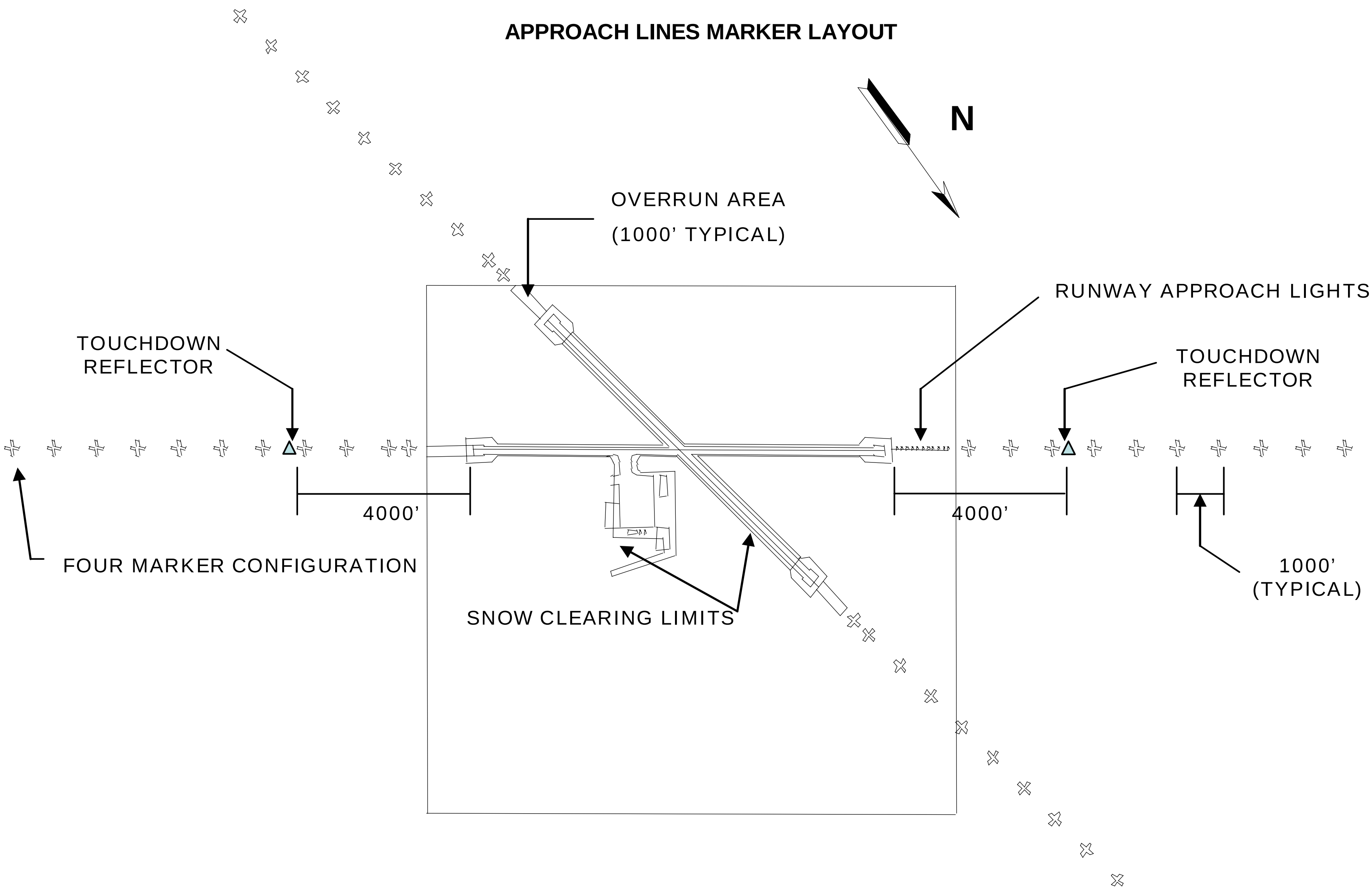

Figure 10. Sea Ice Runway Layout with Dimensions, Showing Markings and NAVAIDS

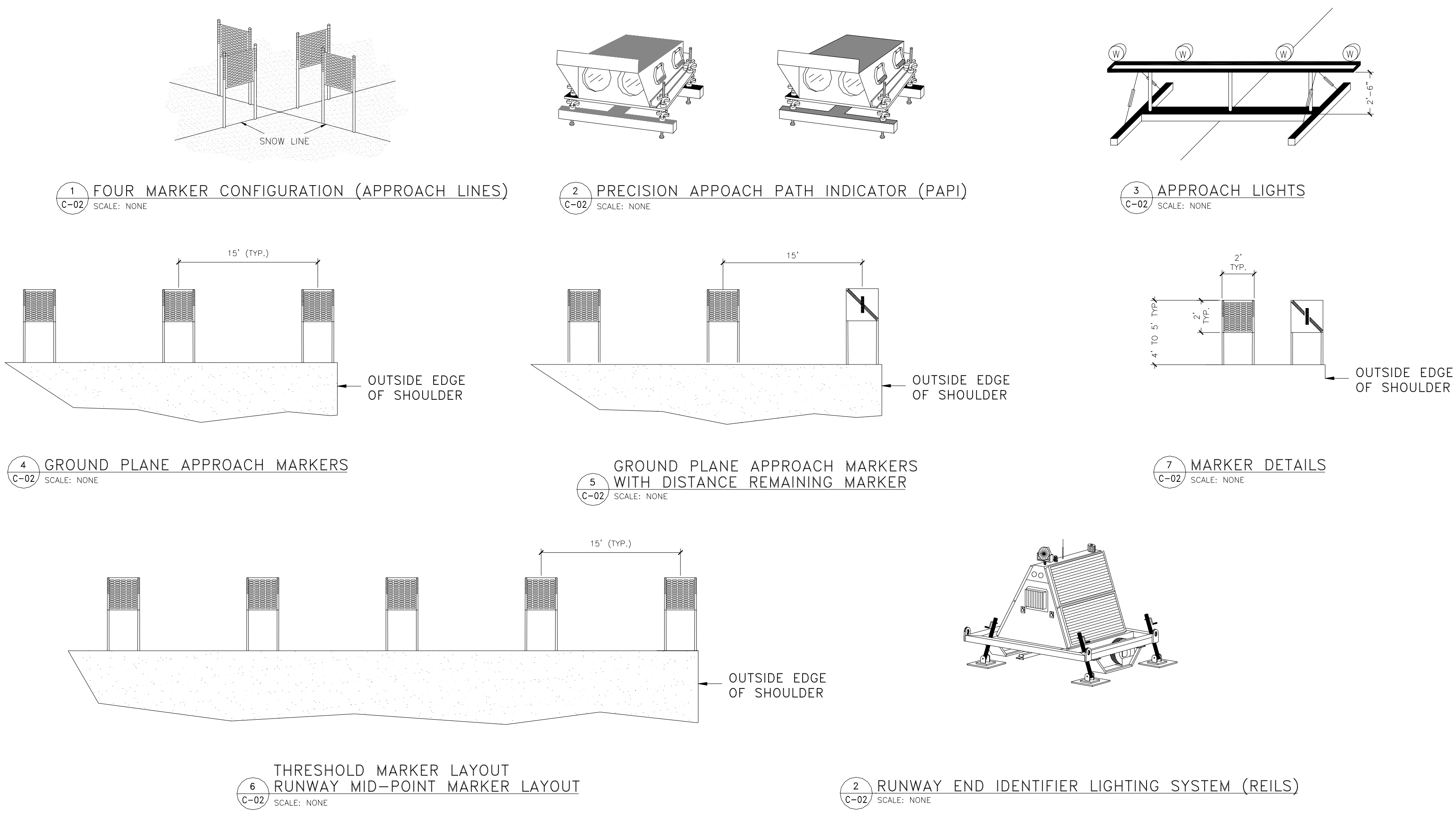

Figure 11. Details of Runway Markers and NAVAIDS
(See Attachment 5 for metric conversion factors)

8.5. Also shown in Figure 10 are the positions of the current suite of NAVAIDS (Tactical Air Navigation [TACAN], runway end identifier lights [REILS], Mobile Microwave Landing System [MMLS], and precision approach path indicator [PAPI] lights). These are also strictly above-surface installations; however, subsurface wiring has been arranged for the NAVAIDS to allow the use of central and displaced power generation.

8.6. Figure 11 shows details of the runway markings and NAVAIDS. Note that all markings and NAVAIDS are only present at the site during the flight periods. At all other times, all surface structures, including buildings and other support structures, are removed from the site to discourage progressive snow accumulation.

8.7. This ETL reflects markings and NAVAIDS to be used at the Sea Ice Runway site. The markings and NAVAIDS shown in Figures 10 and 11 should be considered completely adequate for routine operations. Exact placement details, including dimensional tolerances of runway markers and NAVAIDS, can be found in Air Force Manual (AFMAN) 32-1076, *Design Standards for Visual Air Navigation Facilities*.

9. Operational Waivers to Criteria. The criteria in this ETL are the minimum permissible for C-130, C-141, C-17, and C-5 operations. When deviations exist or occur, an operational waiver must be obtained before starting flight operations. The airfields manager will initiate a written waiver request to HQ AMC/DO for consideration. The waiver must outline all criteria that do not meet the requirements of this ETL. The appropriate airfield survey team will verify existing PLZ dimensions and grades. HQ AMC is the approval authority for waivers of all criteria contained in this ETL.

10. Points of Contact: Recommendations for improvements to this ETL are encouraged and should be furnished to:

Pavement Engineer
HQ AFCESA/CESC
139 Barnes Dr, Suite 1
Tyndall AFB, FL 32403
DSN 523-6334
Comm (850) 283-6334
Fax DSN 523-6218
Email AFCESAReachBackCenter@tyndall.af.mil

Command Pavement Engineer
HQ AMC/A7OI
507 Symington Drive
Scott AFB, IL 62225-5022
DSN 779-0976
Comm (618) 229-0976
Email amc.a7o@amc.af.mil
("Attn: Command Pavement Engineer" in subject line)

Operations Manager
U.S. Antarctic Program, Office of Polar Programs
National Science Foundation
4201 Wilson Blvd. Suite 755
Arlington, VA 22230
Comm (703) 292-8030
Fax (703) 292-9080

Research Civil Engineer
Applied Research Division
USACRREL
72 Lyme Rd
Hanover, NH 03755-1290
Comm (603) 646-4100
Fax (603) 646-4820

ALVIN L. DAY, P.E.
Acting Director of Engineering Support

6 Atchs
1. DCP and RSP Operating Instructions
2. Example Calculations Using Landing and Take-Off and Parking Nomographs
3. Sea Ice Runway Patching Procedure
4. Test Plan for Sea Ice Runway Wheeled Aircraft Operations Certification
5. Conversion Factors
6. Distribution List

DCP AND RSP OPERATING INSTRUCTIONS

A1.1. Device Configuration. For application at the Sea Ice Runway, the DCP device should be operated with a fixed 60°, 20-millimeter (0.8-inch) diameter cone, and an 8-kilogram (17.6-pound) drop hammer. The RSP will be operated with the standard 30°, 11-millimeter (0.4-inch) diameter cone, and a 1.75 kilogram (3.85-pound) drop hammer.

A1.2. Test Method. Penetrometer measurements can be taken at any time of day, at any air temperature, and in any weather conditions (but environmental conditions at the time of testing must be documented). Take snow strength measurements at the locations noted in the field data sheet (see Attachment 4).

Note: Ideally, two persons should work together to take measurements and record penetrometer data.

A1.2.1. Verify that a measuring mechanism is available to accurately note every 25 millimeters (1 inch) of penetration of the penetrometer shaft (e.g., distance marks on the penetrometer shaft or an adjacent measuring rod). The “zero” penetration mark is located at the top of the cone’s pointed end (i.e., at the lowest point on the penetration tip where the maximum penetrometer width occurs).

A1.2.2. Gently place the tip of the penetrometer onto the snow surface and keep the shaft in a vertical position.

A1.2.3. Push the penetrometer vertically into the snow until the widest part of the cone tip is flush with the surface of the snow (i.e., at the “zero” depth mark).

A1.2.4. Gently raise the hammer weight until light contact is made with the top handle. The hammer must not impact the handle when being raised.

A1.2.5. Allow the hammer to freely fall down onto the anvil, thus forcing the cone into the snow.

A1.2.6. Track how many hammer blows (drops) are needed to drive the penetrometer cone 25 millimeters into the surface, as measured by the markings on the shaft or detached measuring device. This will complete Blow Set 1.

Note: 25 millimeters is the penetration goal for each blow set, but if the snow properties suddenly change and the cone quickly penetrates further than 25 millimeters, simply note the actual penetration depth and number of blows in that blow set.

A1.2.7. In the penetrometer field data sheet for that location, write down the number of blows under Blow Set 1, and the penetration of the cone (in millimeters) for that blow set.

A1.2.8. Without moving the penetrometer, begin Blow Set 2, driving the penetrometer another 25 millimeters into the snow by dropping the hammer as many times as needed to achieve this penetration.

A1.2.9. Record the Blow Set 2 data into the appropriate blocks on the field data sheet. Continue the penetration test, 25 millimeters at a time, until the penetrometer tip firmly contacts the supporting sea ice surface.

A1.3. Errors. If the test data are suspicious or erroneous due to problems attributable to operator or equipment error, fix the problem, move the penetrometer 1 meter (3 feet) away from the original test location, and start the test again. Note the event in the “Comments or Observations” block of the field data sheet.

A1.4. Soft Snow. If the penetrometer tests indicate an area of soft snow (only one or two blows gives 25 millimeters of penetration), note the area on the data sheet and mark the location with a pole or flag for further testing and repair. Move 1 meter (3 feet) down the runway and start the test over.

A1.5. Strength Index. The strength index can be determined from the DCP and RSP tests using the formulas given in paragraphs 5.2 and 5.7, respectively. Alternatively, the *Sea Ice Runway Strength Survey Tool* program, a software analysis routine, is available by contacting one of the individuals, at NSF or USACRREL, listed in paragraph 10. This software will ultimately be available in the Pavement Computer Assisted Structural Engineering (PCASE) package of applications.

EXAMPLE CALCULATIONS USING LANDING AND TAKE-OFF AND PARKING NOMOGRAPHS

A2.1. Example 1.

A2.1.1. A measured mean sea ice thickness of 1.83 meters (72 inches) exists on McMurdo Sound. The date is 1 November and the measured mean sea ice temperature for the past week is –17 °C (1 °F). An oversize load, critical to USAP operations, is required in McMurdo. Because of the cargo's size and critical nature, it must be delivered by C-5. In planning for this flight operation, what is the maximum safe gross aircraft landing load given the current sea ice conditions?

A2.1.2. On the landing and take-off nomograph (Figure A2.1) locate 1.83 meters (72 inches) on the left-side vertical axis and draw a horizontal line intersecting the C-5 curve (a). Draw a vertical line from this intersection point to a position representing the scaled location of –17 °C (1 °F) (vertically between the Period 1 band limits of –20 °C (-4 °F) (upper line in band) and –10 °C (14 °F) (lower line in band) (b). From this position, draw a horizontal line to the right-side vertical axis where it can be seen that a maximum C-5 gross weight of 281,820 kilograms (620,000 pounds) can be safely supported for take-offs and landings (c).

A2.2. Example 2.

A2.2.1. Preliminary flight planning for the USAP field season favors operating C-17 aircraft well into Period 2 ice conditions. The final C-17 flight is desired for 12 December. The anticipated gross C-17 weight will be about 168,180 kilograms (370,000 pounds) for this final flight. What sea ice thickness will be required to support landing this planned flight?

A2.2.2. On the landing and take-off nomograph (Figure A2.2) locate 168,180 kilograms (370,000 pounds) on the right-side vertical axis and draw a horizontal line to a position representing the scaled location of 12 December vertically between the Period 2 band limits of about 25 November (upper line in band) and about 15 December (lower line in band) (a). Draw a vertical line from this point to the C-17 curve (b). From this intersection point, draw a horizontal line to intersect the left-side vertical axis, showing that about 1.98 meters (78 inches) of sea ice must be present for safe take-offs and landings.

A2.2.3. Planners can use historical ice data to determine if there is a good likelihood of this ice thickness being present at a particular time. In any case, as the time nears 12 December, actual measured sea ice thicknesses will govern (via use of the nomograph as depicted in Example 1 [Figure A2.1]) exactly what gross C-17 weight can safely be supported.

A2.3. Example 3.

A2.3.1. The C-5 operation presented in Example 1 (Figure A2.1) determined that a maximum gross weight of 281,820 kilograms (620,000 pounds) for landing and take-off is dictated by the sea ice conditions. It is known that about 1.5 hours will be required once the C-5 is parked for off-loading, refueling, and pre-flight preparations. Can the C-5 at 281,820 kilograms (620,000 pounds) safely park on the sea ice for 1.5 hours?

A2.3.2. On the parking nomograph (Figure A2.3) locate 1.83 meters (72 inches) on the left-side vertical axis and draw a horizontal line to intersect with the C-5 curve (a). Then draw a vertical line from this intersection point to a position representing the scaled location of –17 °C (1 °F) vertically between the Period 1 band limits of –20 °C (-4 °F) (upper line in band) and –10 °C (14 °F) (lower line in band) (b). From this position, draw a horizontal line to a point representing the gross aircraft weight (vertically scaled location between provided weight curves) (c). Now draw a vertical line upward to the reflection surface (d). A horizontal line from the reflection surface is then drawn to intersect the parking curve (e). Lastly, a vertical line is then drawn to intersect the horizontal safe parking time axis where it can be seen that the C-5 mission considered will only allow about 25 minutes of parking time before creep failure of the sea ice.

A2.3.3. Two possibilities exist for alleviating this situation. First, and easiest, is to minimize the gross weight of the C-5. While the landing nomograph (Figure A2.1) indicates that a maximum gross weight of 281,820 kilograms (620,000 pounds) can be landed safely, a lesser weight is certainly also safe. If the C-5 gross arrival weight could be reduced to about 215,910 kilograms (475,000 pounds), a parking time of about 90 minutes could be achieved. If the aircraft cannot be reduced to this load level, an alternative is to minimize the landing/parking weight as possible and plan for moving the parked aircraft one or more times during the off-loading process. This is quite inefficient and requires significant planning, but has on occasion been necessary. The distance moved must be greater than two times the overall width of the aircraft (wingspan) and can be in any direction. As soon as the aircraft is parked in its new location, the parking time clock restarts.

A2.4. Example 4.

A2.4.1. A two-hour parking time is required to achieve unloading and back-loading of a C-17 mission very late in the life of the annual McMurdo Sound Sea Ice Runway (30 December). It is expected that the C-17 will have an average weight of 500,000 pounds (226,796 kilograms) during a large part of its parked time. What sea ice thickness will be necessary to support this flight?

A2.4.2. On the parking nomograph (Figure A2.4), locate 120 minutes on the horizontal safe parking time axis and draw a vertical line to intersect the parking curve (a). From this intersection point, draw a horizontal line to the reflection surface (b); and from there, drop vertically to the 226,796 kilograms (500,000 pounds) aircraft load line (c). A horizontal line from this point to a temperature-representative point within Period 3 follows (d). Then draw a line vertically to intersect the C-17 curve (e). From here, a horizontal line can be seen to intersect the sea ice thickness axis at about 2.29 meters (90 inches) (f).

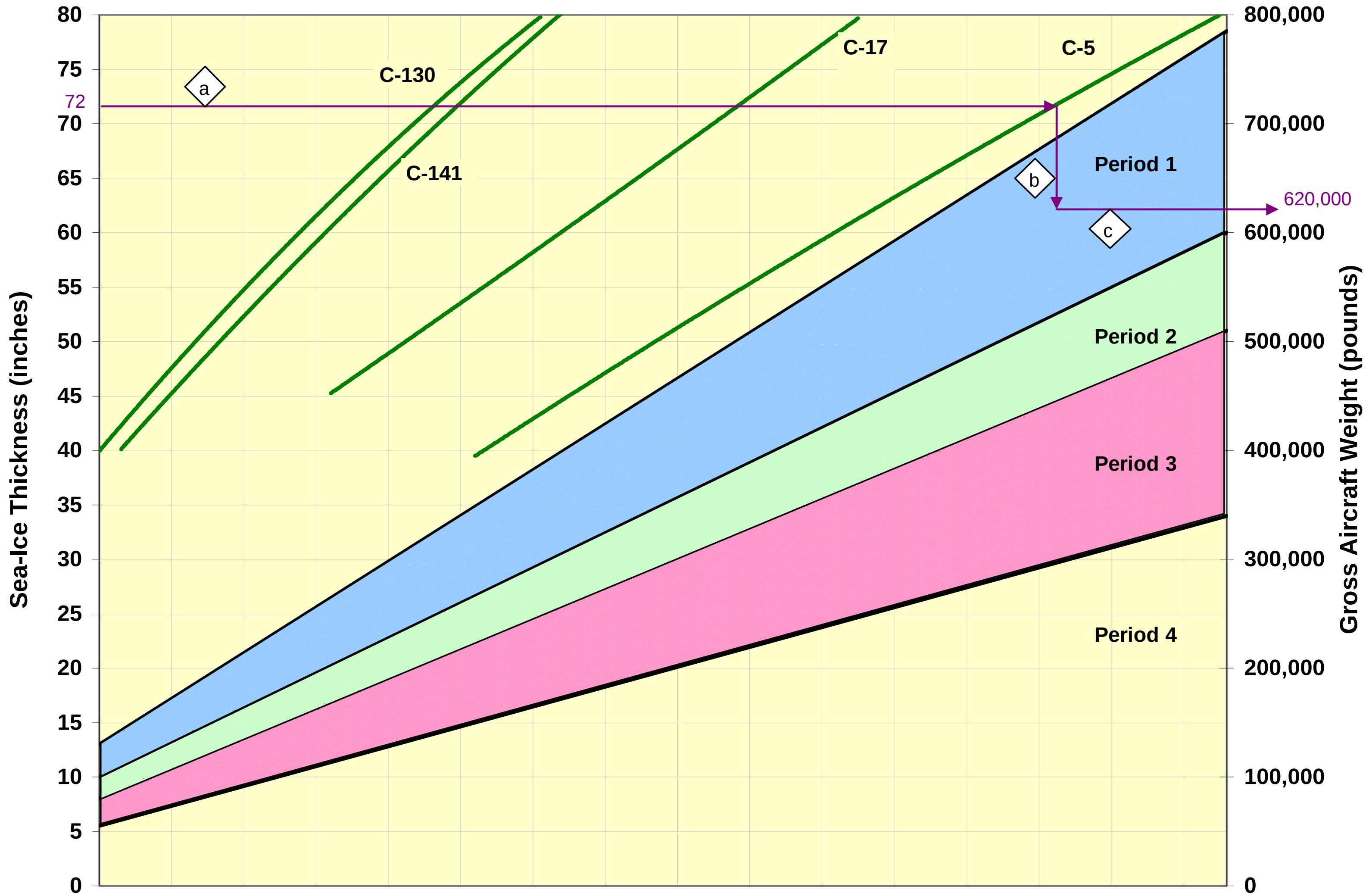

Figure A2.1. Example 1
(See Attachment 5 for metric conversion factors)

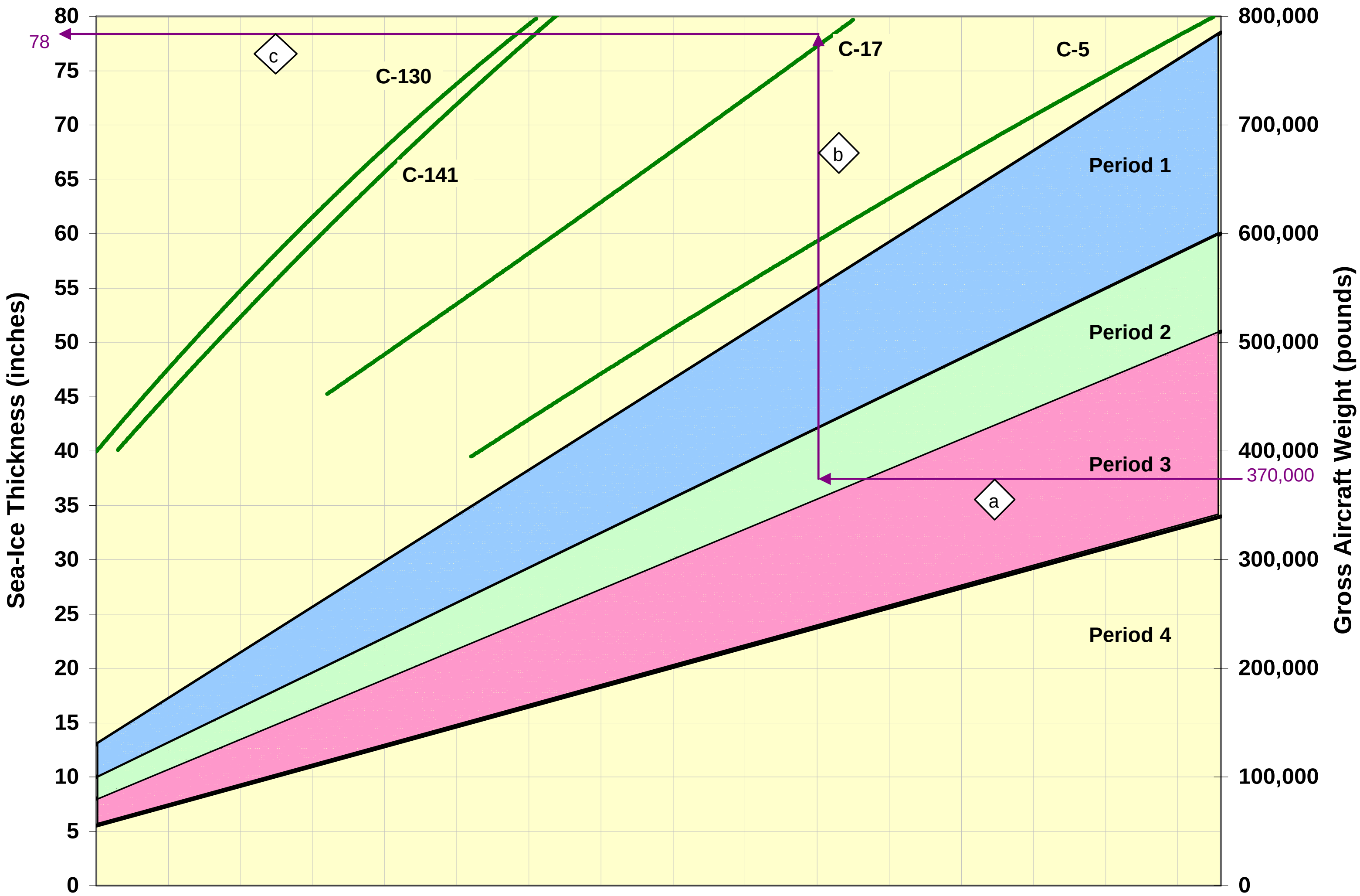

Figure A2.2. Example 2
(See Attachment 5 for metric conversion factors)

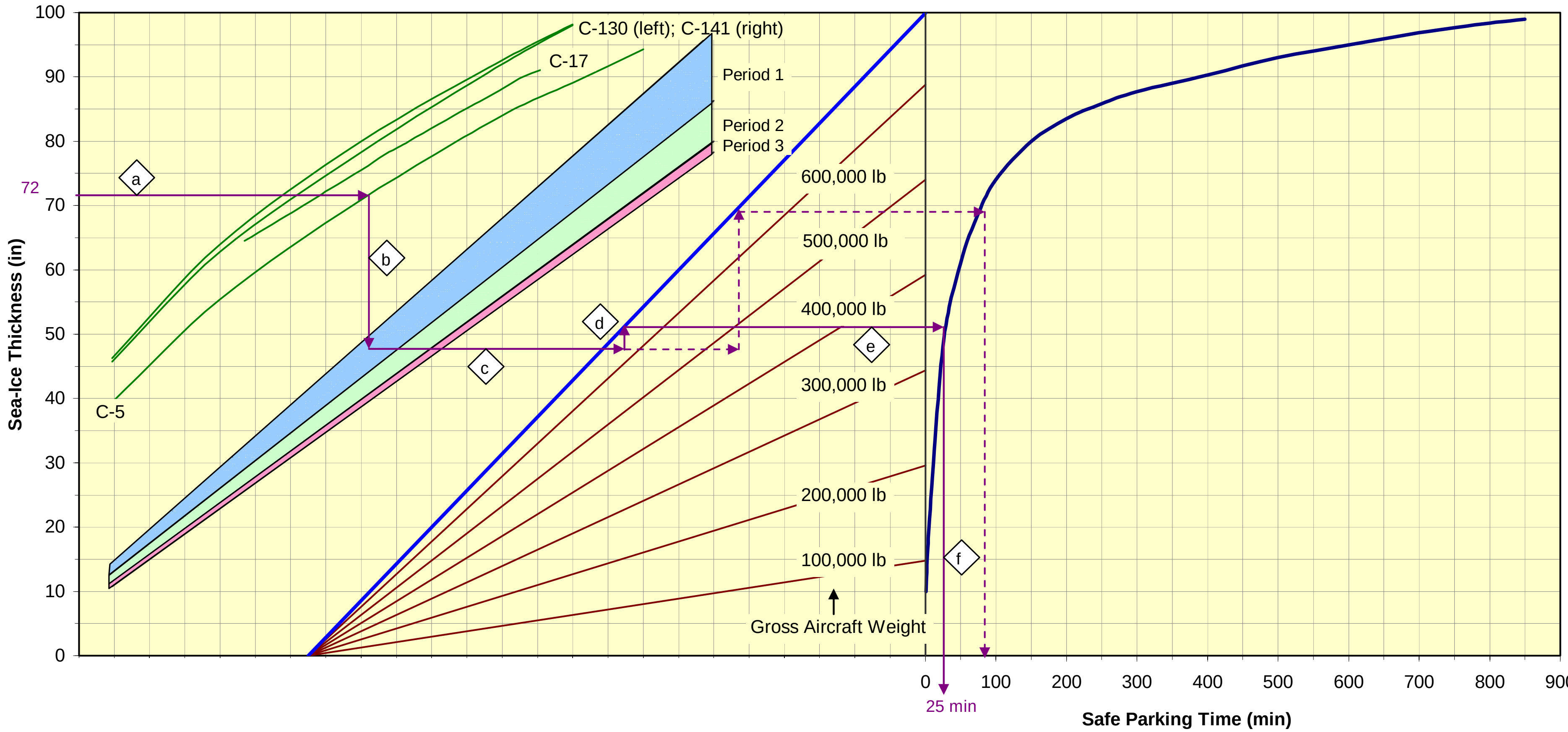

Figure A2.3. Example 3
(See Attachment 5 for metric conversion factors)

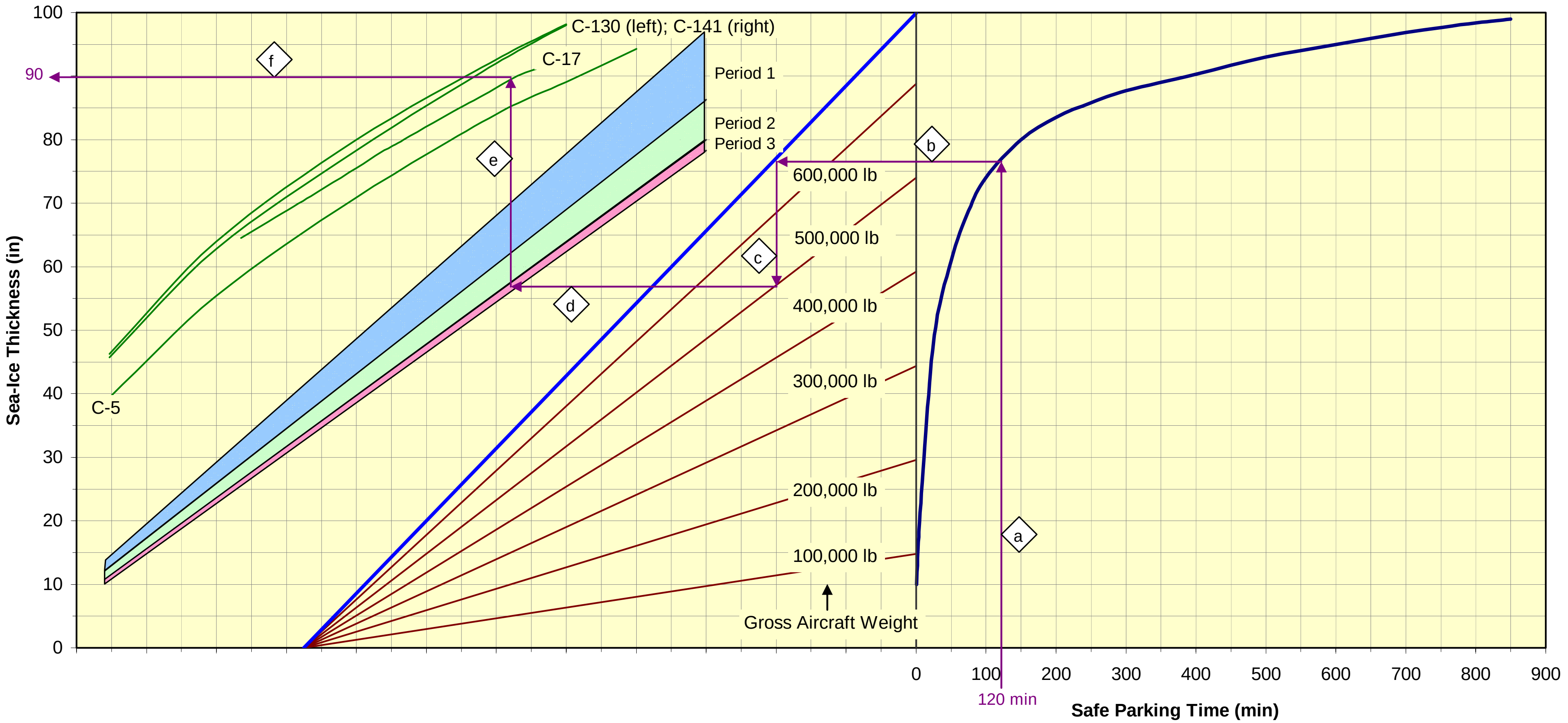

Figure A2.4. Example 4
(See Attachment 5 for metric conversion factors)

SEA ICE RUNWAY PATCHING PROCEDURE

A3.1. Introduction. Infrequently, there may be damage to the runway surface from equipment gouging, solar-induced melt puddle formation, or surface melting caused by windborne or spilled contaminants. These areas will require clean-out, repair, and re-certification. The following patching procedure should be followed. Repair these areas by removing the damaged snow and ice and replacing it with a crushed ice and water "patch" (in the sea ice) and a new snow pavement (on the surface) that provides the required hardness/strength. The repair procedure is based on information in CRREL Monograph 98-1, page 57.

A3.2. Tools. The following tools are needed:

- Long-handled chisel
- Welder's slag hammer or rock hammer
- Coal shovel
- Source of cold, fresh water

A3.3. Patching Procedure. Thoroughly remove all contaminants (including melted and/or refrozen snow and ice) at the site of the repair and dispose of in accordance with site regulations. Remove any loose but clean snow and ice from the damaged area and place it to the side for later use. Clear the faces and edges of the cavity to allow close inspection of the ice along the sides and bottom.

A3.3.1. Sea Ice.

A3.3.1.1. Use the chisel to excavate the area surrounding the failure area to make certain that all of the weak ice has been dislodged. If a large area of the surrounding ice is weak, use one of the large-scale test methods (see CRREL Monograph 98-1, page 47) to break up the weak ice and identify its limits.

A3.3.1.2. Dispose of sea ice removed from the failed area. Pieces of glacial ice (**not** sea ice) roughly the size of a human fist or smaller should be packed into the cavity to fill the hole slightly above its top (approximately 75 to 100 millimeters [3 to 4 inches] higher). Packed snow may be used in the absence of sufficient glacial ice. Any excess material should be removed from the runway.

A3.3.1.3. Slowly fill the hole containing the crushed ice (or packed snow) with cold **fresh** water (ideally, very near 0 °C [32 °F]) to approximately 75% full. Fill the hole by directing the water around the perimeter of the hole. Mix the ice-water slurry in the hole with the chisel and shovel by vigorous vertical probing to ensure that all pore spaces are filled with water and to encourage water to flow into any cracks radiating into the surrounding ice. If using packed snow, gently push down on the patch with the backside of a shovel only; do not probe and stir with a tool. After about an hour, add water to approximately 50 millimeters (2 inches) below the surrounding sea ice surface. Smooth the surface with the backside of a shovel. Allow it to cool for 3 to 4 hours, after which time the surface usually will be frozen over.

A3.3.1.4. Using the chisel, break the top of the ice surface in a number of places (10% of total surface area). Slowly re-flood the patch area to fill the air gap under the ice surface with cold **fresh** water.

A3.3.1.5. Use a brightly colored flag (e.g., orange) to mark the location of the patch on the ice surface. A corner of the flag can be frozen into the surface using cold water. If the runway is not in use, a bamboo or plastic pole with a flag can be pushed into the ice-water slurry to mark the location.

A3.3.1.6. Note the approximate location of the patched area, using the runway markers as a guide for the long axis and the knowledge of the runway width for the other axis. If air operations are in effect, the airfields manager, the air traffic controller, and the flight crew coordinator should be notified that a fresh patch is on the runway and that this area should be avoided for at least 48 hours.

A3.3.1.7. Allow the area to freeze for at least 48 hours before allowing traffic to resume; the flag should then be removed. If possible, the patched area should be "dressed" with the chisel-tooth grader blade to blend its edges into the surrounding ice surface and to provide a uniform surface texture.

A3.3.1.8. Following the glacial ice repair, the site must be re-certified using the procedures given in paragraph 7.2 et seq. if the repair area is greater than 0.4 square meter (4.3 square feet).

A3.3.2. White Ice.

A3.3.2.1. For a white ice surface requiring repair, whether or not the previous procedures (paragraph A3.3.1 et seq.) were required to patch the underlying sea ice, ensure that all weak, contaminated, or damaged pavement is stripped from the sea ice surface.

A3.3.2.2. Fill the area with clean, fresh (no more than one-year-old) snow using hand tools or mechanical equipment, depending on the volume of snow required.

A3.3.2.3. Level the snow surface with a light drag or snow plane, or a wide-tire (1 meter), low-ground-pressure (tire inflation pressure of 100 kilopascals [kPa] [14.5 pounds per square inch (psi)] or less) wheeled vehicle.

A3.3.2.4. Use a compaction roller (used to initially construct the white ice surface) to level the entire patched area using 85% of the final tire pressure and gross load used during initial construction. Allow the snow to "rest" for 24 hours and repeat compaction rolling at 95% of the final tire pressure and gross load. After another 24-hour rest, repeat compaction rolling at 100% of the final tire pressure and gross load used during initial construction. The patched area will be ready to accept routine aircraft traffic following another 24-hour rest period, but this must be verified with certification tests as given in paragraph 7.3 et seq.

TEST PLAN FOR SEA ICE RUNWAY WHEELED AIRCRAFT OPERATIONS CERTIFICATION

A4.1. Introduction. This test plan documents and explains the required steps, methods, and tools required to certify the Sea Ice Runway for wheeled aircraft operations. The primary attributes that govern certification are dimensions and grades, markings, pavement strength (hardness), and snow and ice temperature profiles. Use this test plan, the accompanying charts (Figures A4.1 and A4.2), and the *Ice Runway Strength Survey Tool* program (available by contacting one of the individuals, at NSF or USACRREL, listed in paragraph 10) to achieve a satisfactory runway evaluation and analysis.

A4.2. Certification Process.

A4.2.1. Dimensions and Grades.

A4.2.1.1. Measure features in the runway area (as depicted in Figures 3, 4, and 5). Use available and expedient survey methods and tools (e.g., taping, measuring wheel, transit, laser) to verify that the dimensions and grades of the following airfield components are as required in Tables 1 through 4.

- Runway
- Shoulders
- Overrun area (each end, if present)
- Taxiway
- Apron (refuel, load/unload, turnaround)
- End clear areas
- Lateral clear areas

A4.2.1.2. Verify dimensions and grades of each feature at the approximate locations shown in Figures 3, 4, and 5. Note that some areas and zones will blend seamlessly (without indication) into other areas, such as where the runway width transitions to the shoulders. In these situations, simply measure and verify that the combined dimensions of the features are per specification.

A4.2.1.3. On Figures 3, 4, and 5, place a check mark (√) by each dimension and grade that has been measured and approved, and place an **X** by any dimension that fails the inspection, noting where the failure is located. Measurements that fail the inspection must be documented and brought to the attention of the airfields manager.

A4.2.2. Markings and NAVAIDS. AFMAN 32-1076 governs the placement of markings and NAVAIDs.

A4.2.2.1. Check that markings and NAVAIDS are in the correct positions and properly annotated as shown in Figure 10.

Note: Direct on-snow marking is prohibited.

A4.2.2.2. Verify that the bottom of the marker (flag) is at least 1 meter (3 feet) above the snow surface. Marker dimensions (which vary depending on required markings) must conform to Figure 11.

A4.2.2.3. Check that flags are attached to frangible (break-away or bend-away) poles. Suitable poles can be made of common bamboo or lightweight plastic, but must not be metal or large, solid wood (e.g., 100-millimeter by 100-millimeter [4-inch by 4-inch] posts).

A4.2.2.4. Each flag will be stretched out between two poles and attached to the poles by means that are wind-proof and sturdy (but removable), such as with clamps and cords.

A4.2.2.5. On Figure 10, place a check mark (√) by each flag that is properly placed and marked, and place an **X** by any missing, misplaced, or improperly marked flags. Flagging problems must be documented and brought to the attention of the airfields manager.

A4.2.3. Pavement Hardness (Strength) (**Note**: Only required when white ice pavement is present).

A4.2.3.1. Measure snow pavement hardness with a DCP or RSP at the locations shown in Figure A4.1 (at the circles). Penetrometer measurements can be taken at any time of day, at any air temperature, and in any weather conditions, following the procedures presented in Attachment 1. A field data sheet (Figure A4.2) is provided for logging measurements made with a DCP. All runway surface features meant to carry an aircraft wheel load will be required to achieve the same minimum and average strength ratings.

A4.2.3.2. The layout of data entry in the field data sheet (Figure A4.2) is designed to allow the certification team to walk the runway in an efficient path while taking DCP or RSP hardness and temperature measurements. These field data will later be entered at McMurdo Station into a computer database for analysis and results.

A4.2.4. Snow Temperature (**Note**: Only required when white ice pavement is present).

A4.2.4.1. Surface and subsurface temperatures will be measured with a portable thermometer on the day of review at the locations shown in Figure A4.1 (marked with an X). Enter these data into the field data sheet (Figure A4.2). Snow temperature measurements can be taken at any time of day, at any air temperature, and in any weather conditions, but ideally should coincide with strength measurements.

A4.2.4.2. For the portable thermometer test, a stainless steel temperature probe is pushed into the snow on the surface and at depths of 50 millimeters (2 inches), 100 millimeters (4 inches), and 150 millimeters (6 inches) (or the base of the white ice pavement), and is held against the snow for 30 seconds to gain an accurate reading. If the snow is too hard to insert the probe, a small trench should be cut out of the snow pavement to allow the probe to be inserted horizontally. The temperature probe should be calibrated yearly.

A4.2.5. Sea Ice Temperature (**Note:** Required with or without the presence of white ice pavement).

A4.2.5.1. Paragraph 7.2 et seq. indicates the importance of temperature measurements for structural certification. Sea ice temperature is ideally measured with a continuously recording imbedded sensor string located at a number of representative locations. If such sensors are not available, manual temperature readings must be taken ***daily*** during the warmest (air temperature) three-hour period during the day, any time air temperature is greater than –7 °C (19 °F) for an exposed sea ice surface or –5 °C (23 °F) for a runway with a snow pavement in place. These manual readings should be performed at the locations given in Figure A4.1, at a depth of 10 millimeters (0.5 inch) below the sea ice surface.

A4.2.5.2. If sea ice temperatures (from either the buried probes or portable thermometer measurements) are above the minimums presented in paragraph 7.2.1.1, proof rolling tests are required to inspect for potential melt damage in the warm areas. Proof rolling is described in paragraph 7.2.1.1 and CRREL Monograph 98-1.

A4.2.6. Snow Depth. Measure snow pavement thickness at the locations indicated in Figure A4.1. Typically, DCP (or RSP) measurements at these same locations result in a reliable measure of snow depth.

A4.2.7. Data Reduction and Analysis. With the field data sheet in hand, re-enter the penetrometer data (blows, and penetration per blow set) and the portable thermometer temperature data into the *Ice Runway Strength Survey Tool* program (contact the individuals, at NSF or USACRREL, listed in paragraph 10 for access to this program). The program will process the data and graph the DCP index value for each runway location tested, and the results will also be automatically compared to the strength go/no-go criteria given in Table 5. Finally, the temperature data will be automatically compared to the upper limit of –4 °C (25 °F) (exposed sea ice), or –6 °C (21 °F) (white ice pavement over sea ice) with a final result provided.

A4.2.8. Approval and Documentation Storage. The certification team leader and the airfields manager will sign the final results from the data analysis. These signed documents and the electronic and hardcopy data and analysis results will be provided to and maintained by the airfields manager, and will also be provided to the certification team leader for forwarding to HQ AMC/A7OI.

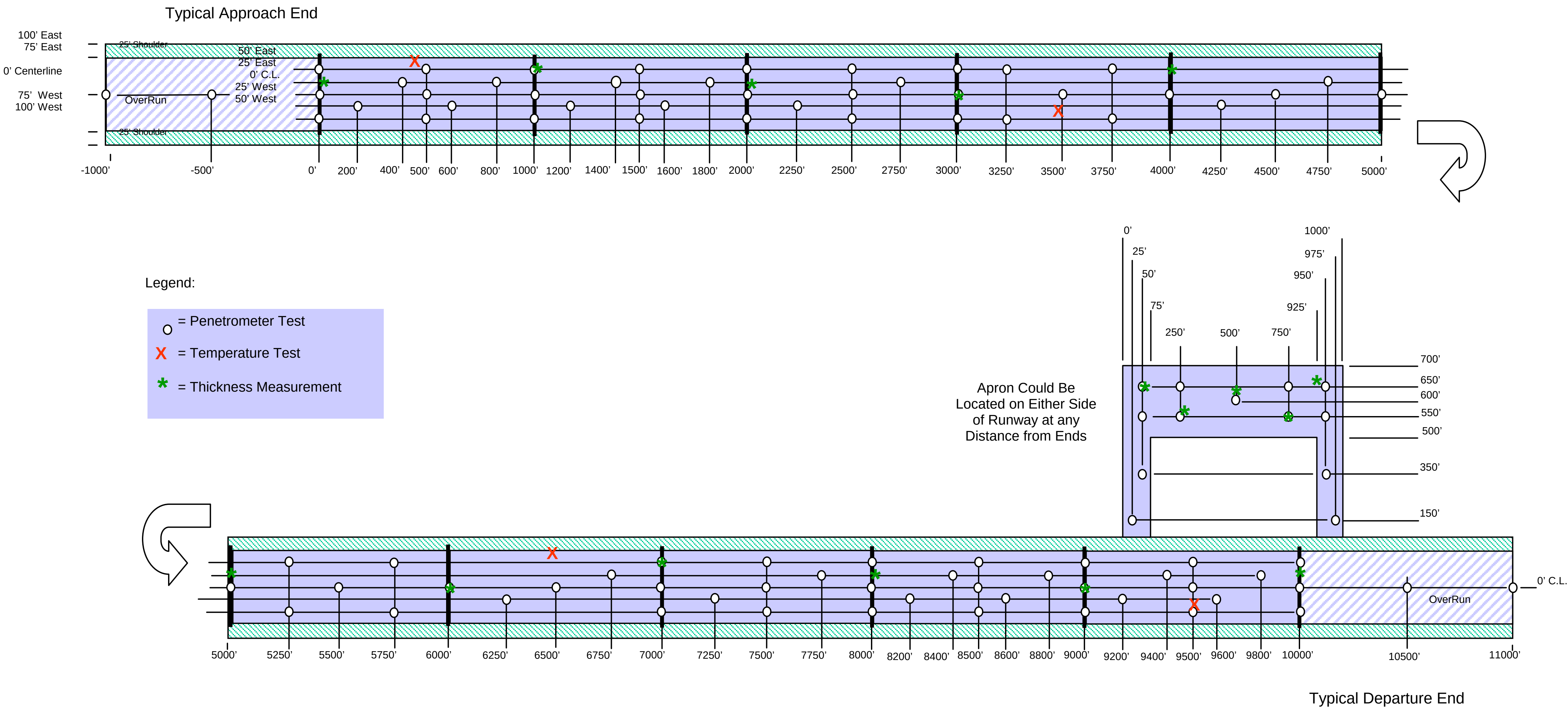

Figure A4.1. Locations for Surface Properties Measurements

South End

Sea Ice Runway Snow Pavement Hardness and Temperature - Field Data Sheet

DCP - Dynamic Cone Penetrometer

1. Read Separate Instructions On Proper Use and Care Of The DCP Device
2. Obtain Penetration and Temperature Data at Locations Shown Below (Also See Figure A4.1).
3. Re-enter all Field Data (Blows, Accumulated Depths, Temperature) into the Runway Hardness and Temperature Analysis Program (Excel).
4. Print out Field Data Sheet and Analysis Program Results and retain at on-site location.

The Data Entry Block
(See Example Data in chart below)

Number of Blows (Blow Set) →	6	25	← Accumulated Penetration Depth (mm) Per Blow Set (goal is a minimum of 25 mm for each blow set)

DCP Penetrometer Field Data

MAIN RUNWAY

DCP Data Collected By: ______________________ Collection Date: ______________ DCP Drop Weight: 17.6 lb (8.6 kg)

Accumulating Depth (mm) → (Note: The depth achieved with each Blow Set should be at least 25 mm)

Data Collection Locations		Blow Set 1		Blow Set 2		Blow Set 3		Blow Set 4		Blow Set 5		Blow Set 6		Blow Set 7		Blow Set 8		
Distance Down Runway, Feet (Starting at West End)	Lateral Location, Feet (From Runway Centerline)	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Comments or Observations
	Example Data →	7	25	8	50	8	75	7	100	5	125	5	150	6	175	6	200	Gas spill 2' away - soft, needs patch
(-) 1000 West OverRun	0																	
(-) 500 West OverRun	0																	
0	(+) 50																	
0	0																	
0	(-) 50																	
200	(-) 25																	
400	(+) 25																	
500	(+) 50	Temperature Test. Surface:_________°C, 5cm:_________°C, 10cm:_________°C, 15cm:_________°C																
500	(+) 50																	
500	0																	
500	(-) 50																	
600	(-) 25																	
800	(+) 25																	
1000	(+) 50																	
1000	0																	
1000	(-) 50																	
1200	(-) 25																	
1400	(+) 25																	
1500	(+) 50																	
1500	0																	
1500	(-) 50																	
1600	(-) 25																	
1800	(+) 25																	

(partial data sheet shown)

Figure A4.2. Sample Field Data Sheet (Configured for DCP Measurements)

CONVERSION FACTORS

TO CONVERT	TO	DIVIDE BY
LENGTH		
millimeters (mm)	inches (in)	25.4
centimeters (cm)	inches (in)	2.54
meters (m)	inches (in)	0.0254
meters (m)	feet (ft)	0.3048
meters (m)	yards (yd)	0.9144
kilometers (km)	miles (mi)	1.60948
AREA		
square millimeters (mm^2)	square inches (in^2)	645.16
square centimeters (cm^2)	square inches (in^2)	6.4516
square meters (m^2)	square inches (in^2)	0.00064516
square meters (m^2)	square feet (ft^2)	0.09290
square meters (m^2)	square yards (yd^2)	0.83613
square kilometers (km^2)	square miles (mi^2)	2.59043
square kilometers (km^2)	acres	0.00404
VOLUME		
cubic millimeters (mm^3)	cubic inches (in^3)	16,387
cubic centimeters (cm^3)	cubic inches (in^3)	16,487,000
cubic meters (m^3)	cubic feet (ft^3)	0.028317
cubic meters (m^3)	cubic yards (yd^3)	0.764559
MASS		
kilograms (kg)	pounds (lb)	0.45359
FORCE		
Newtons (N)	pounds (lbf)	4.44822
STRESS		
kiloPascals (kPa)	pounds per square	6.89476

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